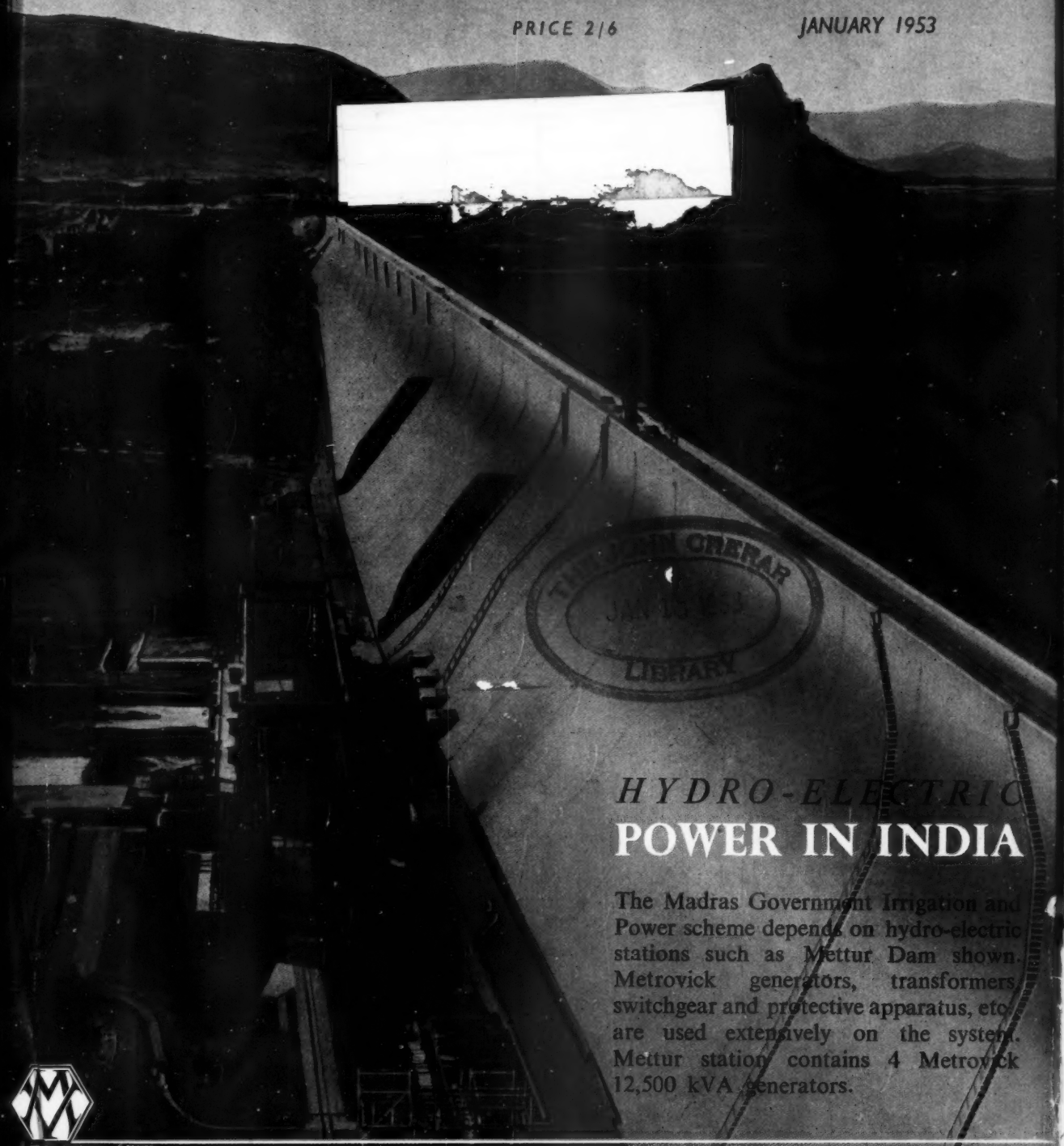
TJ052
W31

Water Power

INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER

PRICE 2/6 JANUARY 1953



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HYDRO-ELECTRIC
POWER IN INDIA

The Madras Government Irrigation and Power scheme depends on hydro-electric stations such as Mettur Dam shown. Metrovick generators, transformers, switchgear and protective apparatus, etc. are used extensively on the system. Mettur station contains 4 Metrovick 12,500 kVA generators.

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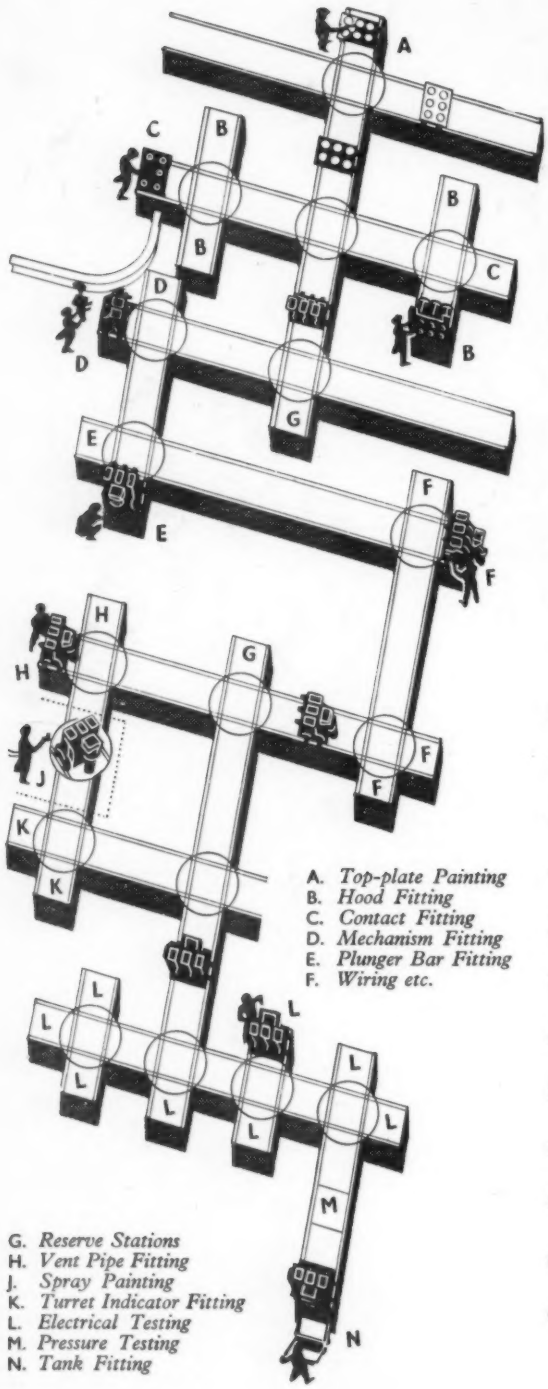

A. *Top-plate Painting*
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IT HAS BEEN SAID that switchgear can only be as good as the production techniques employed in its manufacture and we have long recognised the truth of this assertion. In the old days, when the whole production resources of the company could be concentrated on a few designs, it was comparatively easy, given good craftsmen, to change and improve as one went along. Now, when the manufacturing problem is one of batch production of a large variety of components, new techniques have to be worked out to the last detail before production begins. The successful handling of a recent problem shows what we mean. The Production Engineering Staff were responsible for the introduction of an assembly line for Class 'C' switchgear circuit breakers on which all breakers for 3·3 kV to 15 kV and 100 MVA to 350 MVA are now built, tested and inspected, ready for despatch. Our primary concern is designing and producing switchgear, so if you have any transmission or control problems why not talk to us.

If you want to talk switchgear ... talk to Reyrolle

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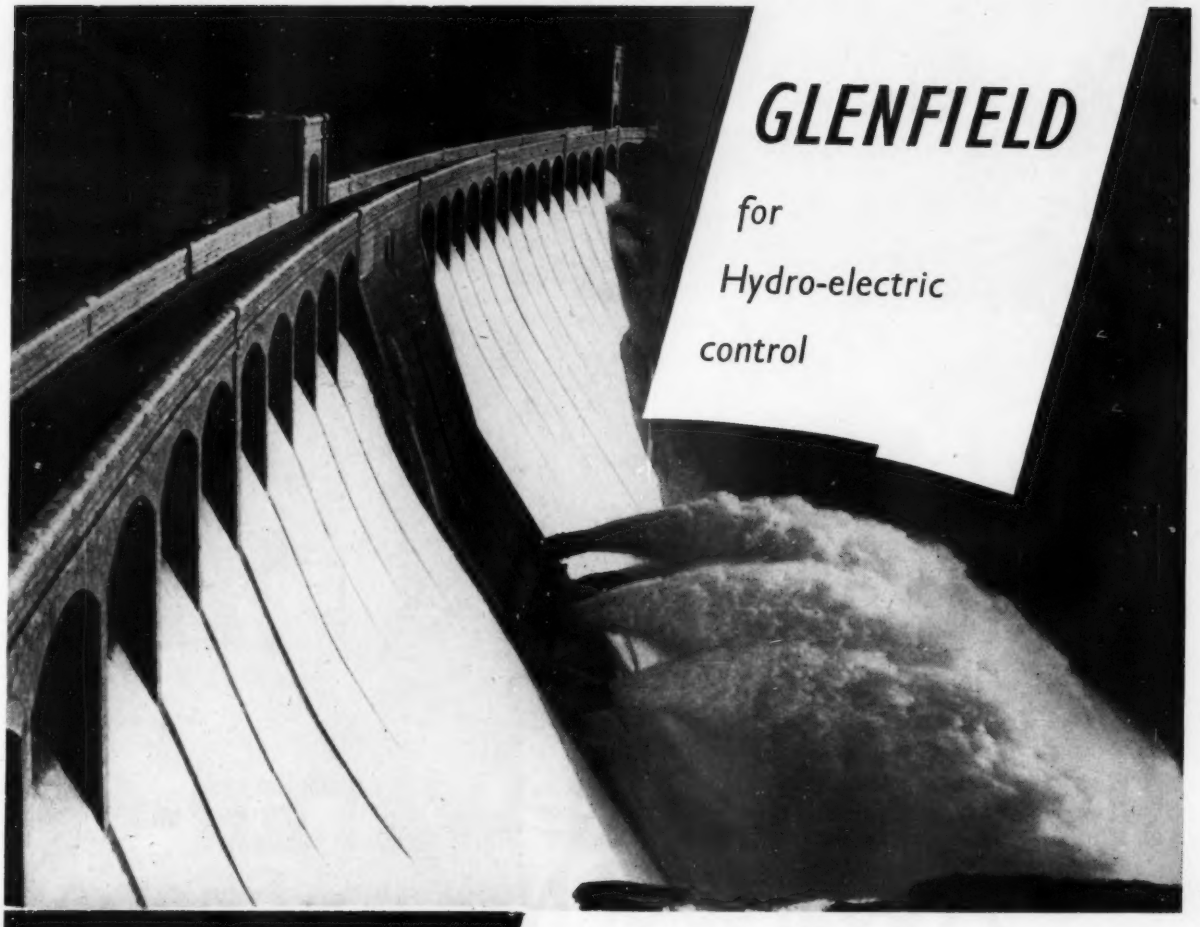


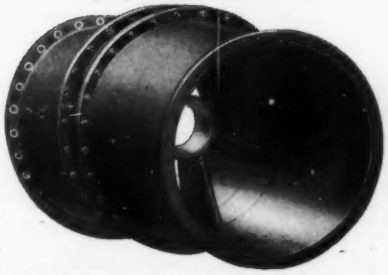
GLENFIELD

for

Hydro-electric

control

JET DISPERSERS



GLENFIELD JET DISPERSERS are in use throughout the world on points of free discharge.

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To result in the harmless dissipation of the issuing jet, without vibration or erosion either of the disperser itself or of the area on which the discharge falls whether into river bed– tunnel—or ditch.

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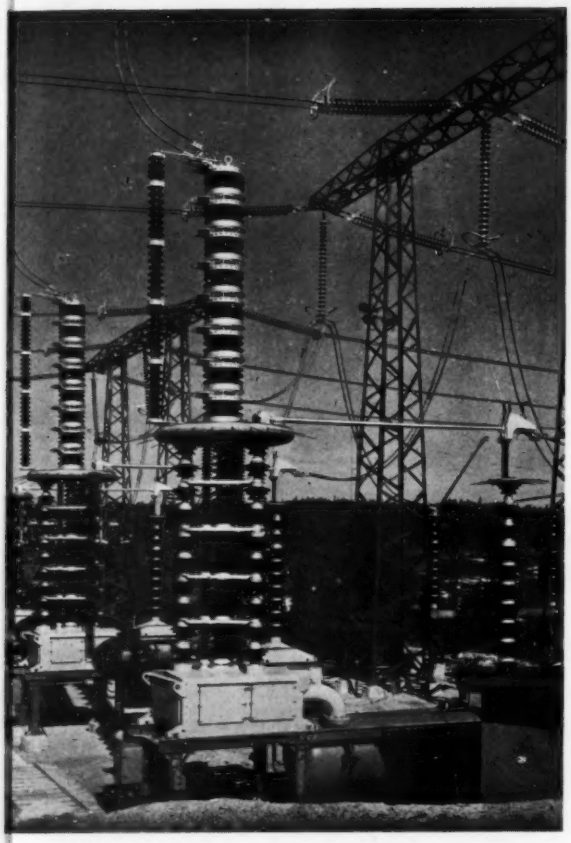
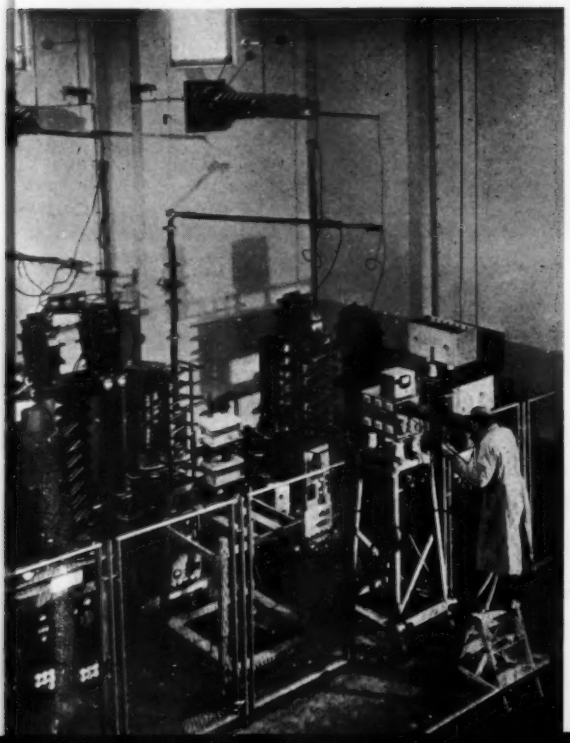
POWER by SMITH

Progress in Power Transmission



ve: A 380 kV air-blast circuit breaker

ow: Trial plant for research on high-voltage mercury arc valves



The past

During the seven decades of its existence ASEA have been responsible for pioneering work in many branches of electrical engineering. In 1890 Swedish and English patents were taken out for the three-phase system. The first three-phase generator, transformer and motor were completed and tested at the beginning of 1891, and in 1893 ASEA built a 9 mile long 9500 V three-phase transmission system capable of transmitting 100 h.p.

Today

The year 1952 marks one of the milestones in the history of power transmission, being the year in which the first 380 kV A.C. power line in the world was commissioned. Practically the entire electrical equipment required for the terminal stations of the line sections, which together form a 600 miles long power line capable of transmitting about half a million kVA, was supplied by ASEA, who also undertook a considerable portion of the scientific investigation and technical development work necessary to translate plans into facts.

Looking ahead

The 380 kV system having proved highly satisfactory in every way, it is confidently anticipated that its use will be greatly extended in the future. There are certain power transmission problems, however, which can be solved more economically by the use of high tension D.C., such as submarine transmission and in some instances even cross country transmission. For a long time past ASEA have carried out an extensive research and development programme, two experimental plants have been in operation for a number of years and a commercial D.C. transmission project for Sweden is now in course of preparation. Painstaking pioneer work has given ASEA a leading position in high voltage power transmission and the firm has both the practical experience and the resources needed to tackle either type of high power transmission system.

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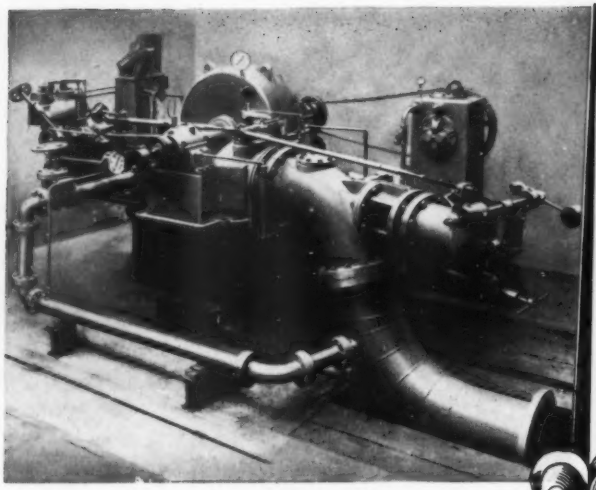
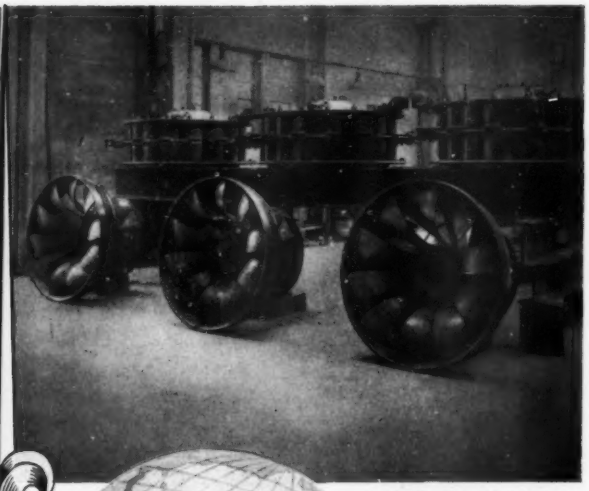


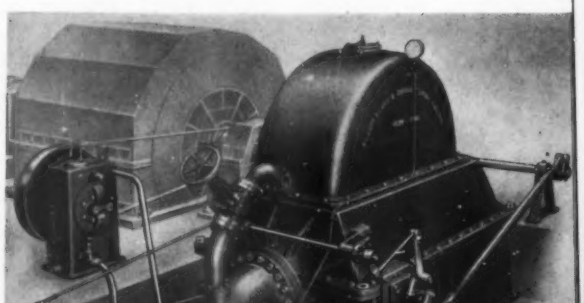
ICELAND—1,100 H.P. Turgo Impulse Wheel for the River Fossa Development of the State Electricity Authority.



TIBET—Three 204 H.P. Open Penstock Francis Turbines for the Lhasa Hydro-Electric scheme.

WATER TURBINES

FOR THE FOUR CORNERS OF THE EARTH



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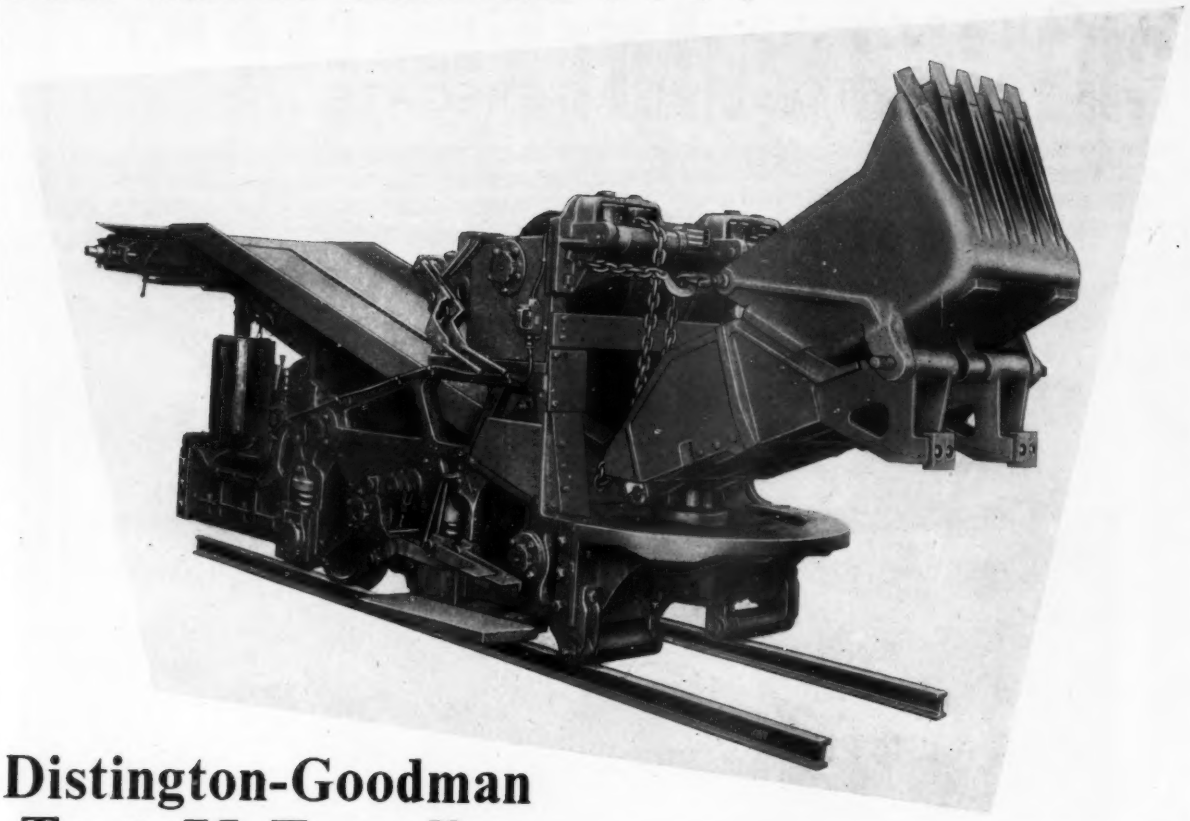

Distington-Goodman Type 75 Tunneller

The clean-up width of the Type 75 Tunneller ranges from 13 feet to 20 feet 9 inches according to the length of boom fitted.

This type of machine can be built for track gauges as narrow as 24 inches or as wide as 42 inches although the gauge may determine the maximum length of boom that can be fitted. Dual gauge machines have been designed to use a narrow gauge track for locomotion, and a wider track to give greater stability to the machine during loading operations.

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LOADING CAPACITY cu. ft. per minute depending on size of dipper		82 101 121
LOADING CYCLES PER MIN.		6
TRAMMING SPEED ft. per min.	FORWARD	180
	REVERSE	123

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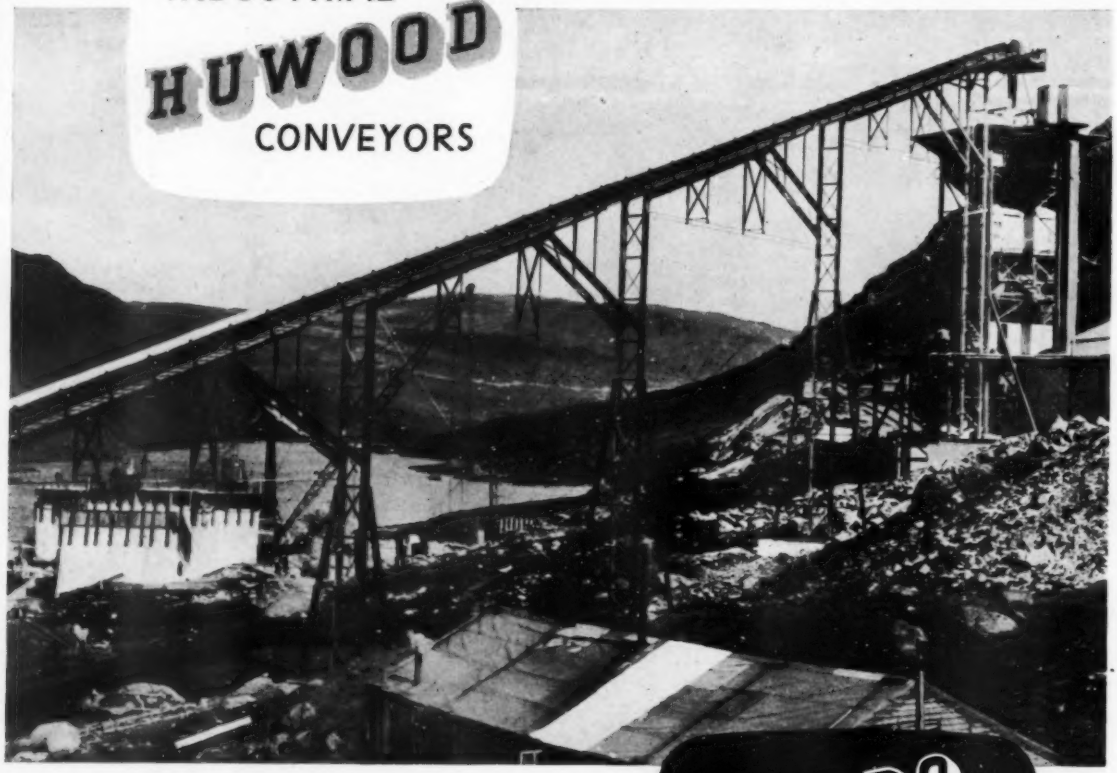

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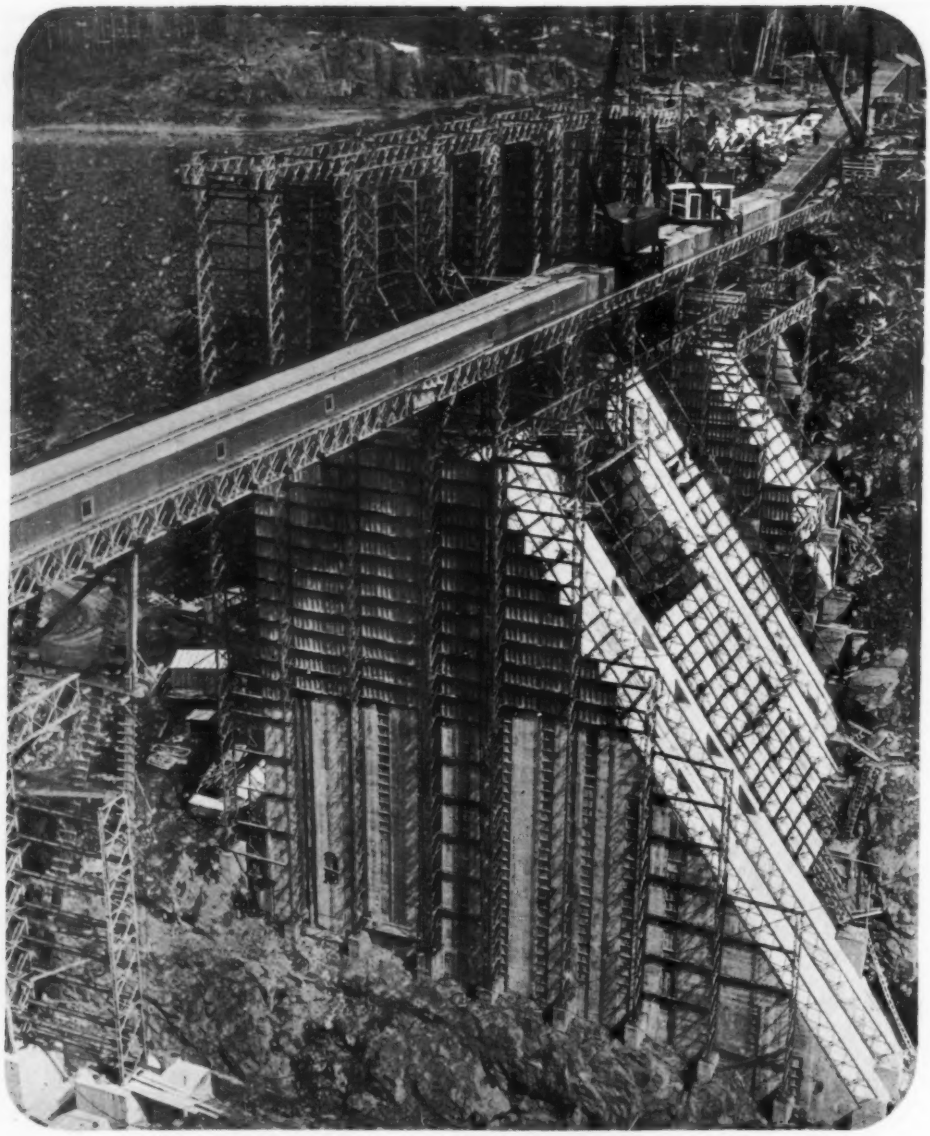

Photograph by courtesy of the Ontario Hydro Electric Commission

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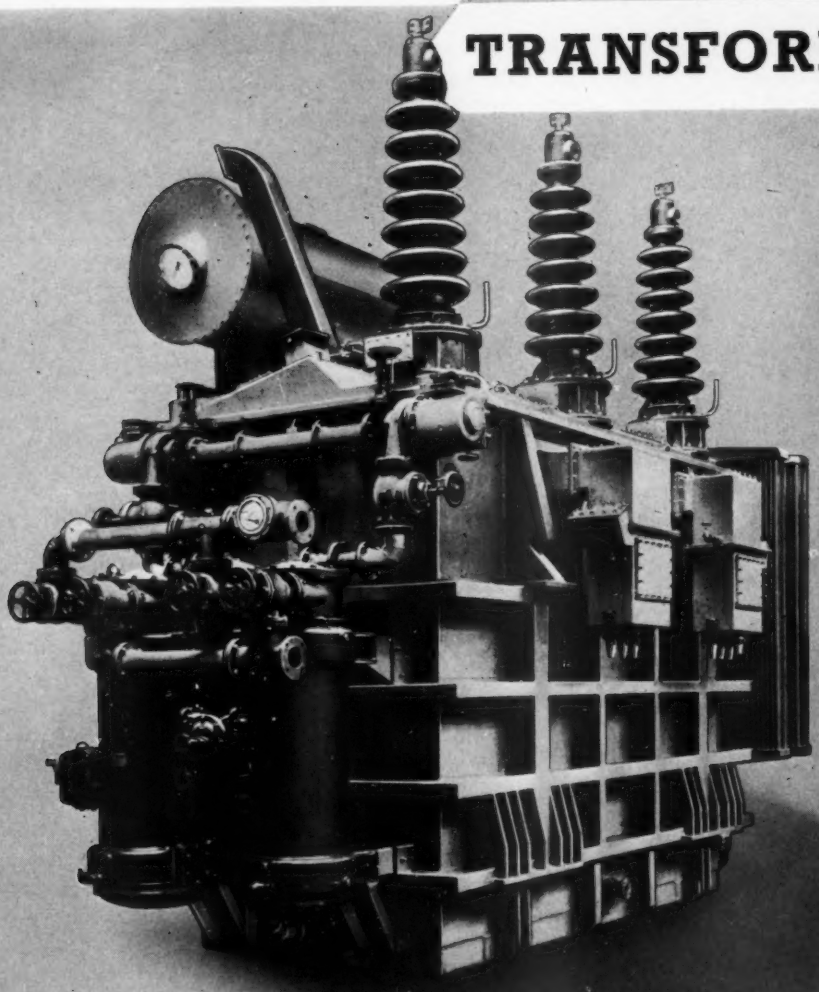

Illustration shows a 20,000 kVA, 132,000/11,000-volt water-cooled transformer typical of many supplied for Scottish hydro-electric schemes.

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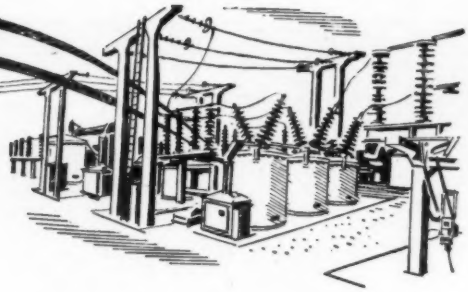

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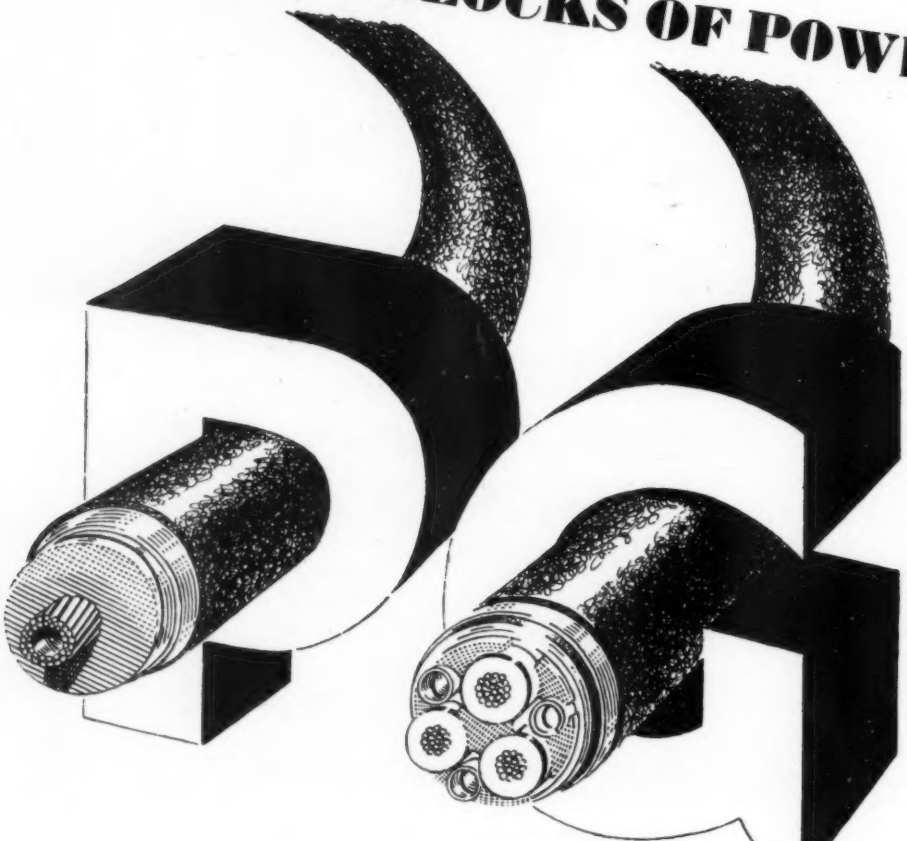

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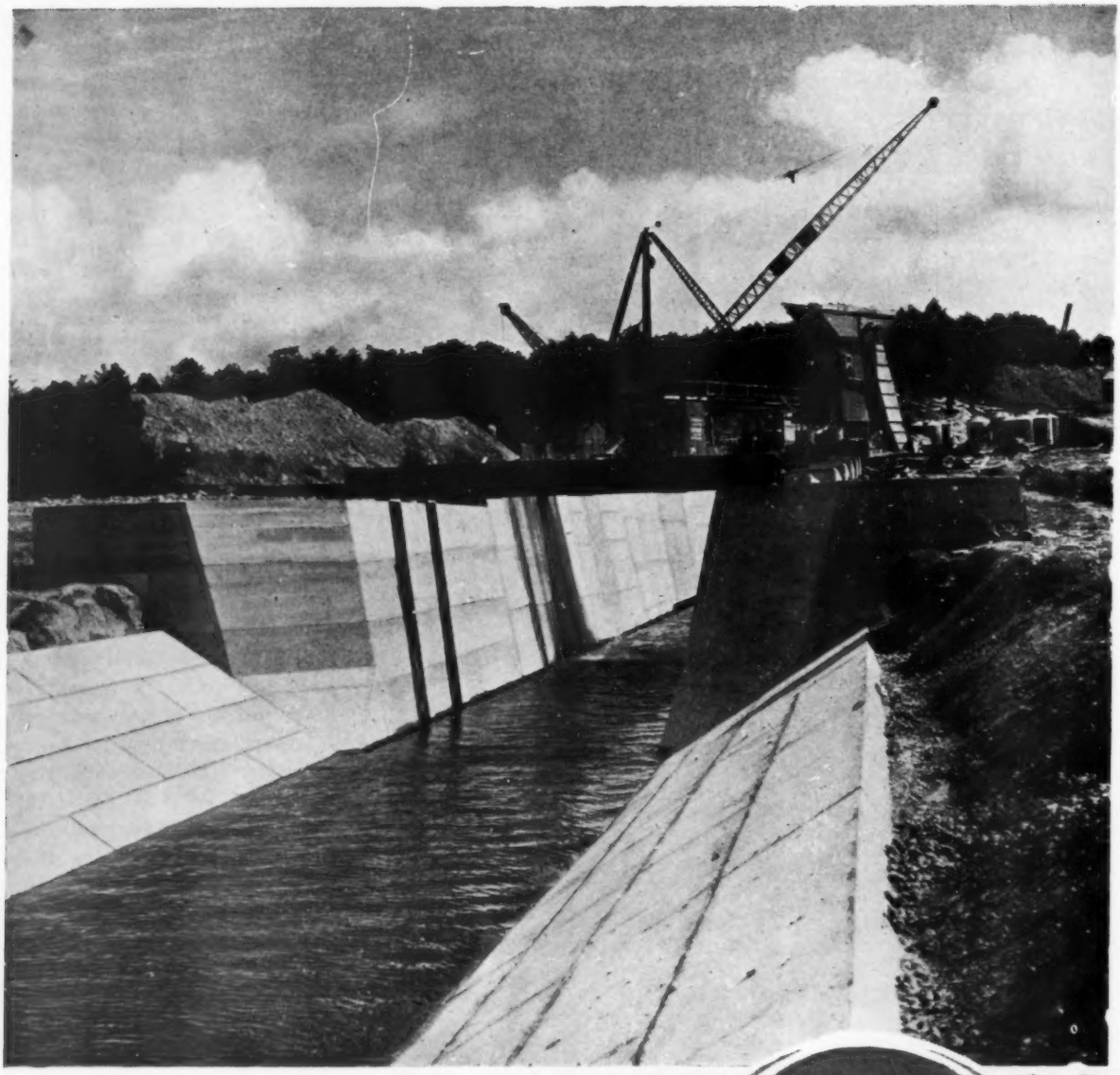

Work on the diversion tunnel and channel at the Weir Wood Reservoir Contract, which is one of the water conservation schemes being carried out by the Company

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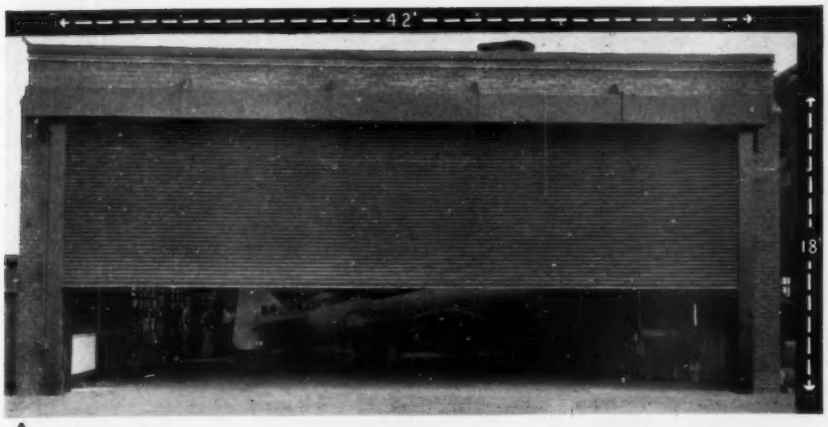

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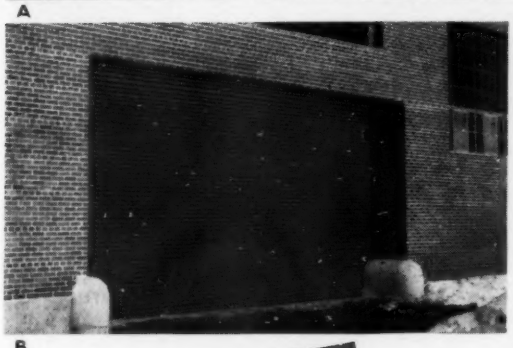

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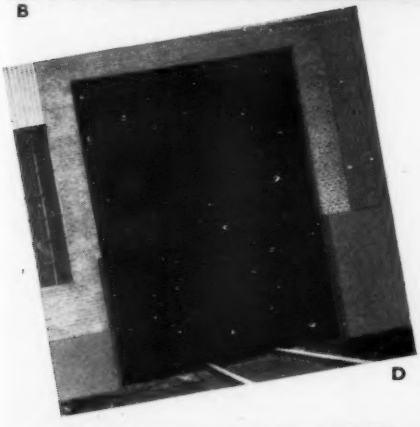

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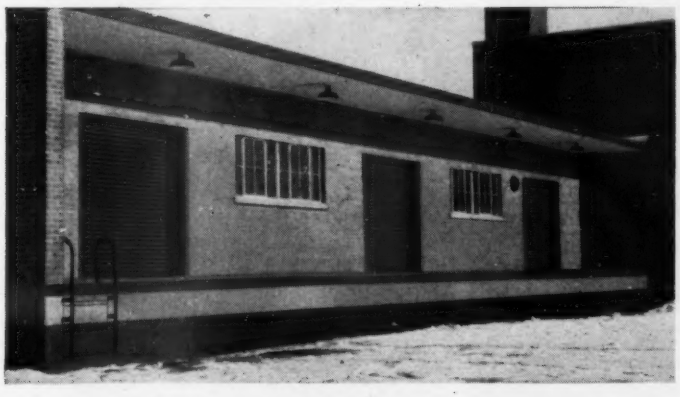

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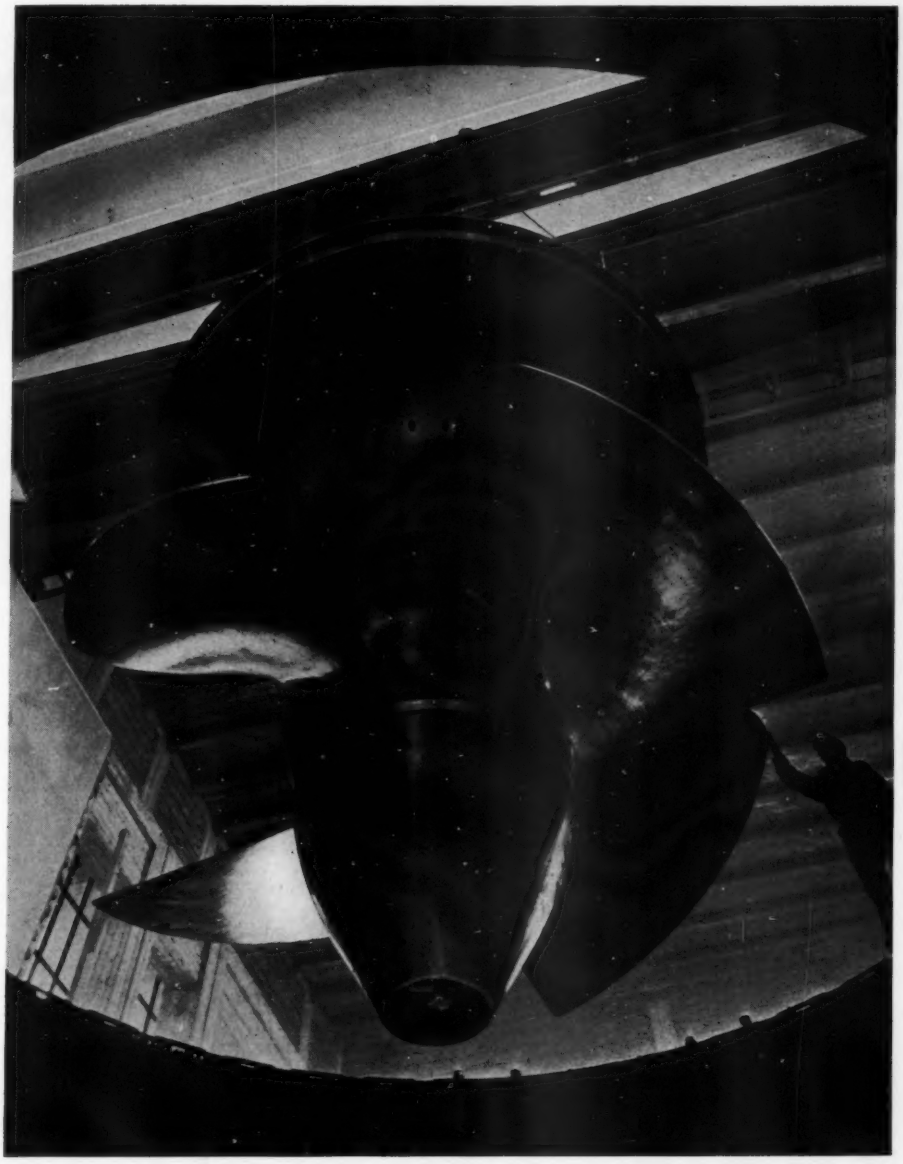

Kaplan turbine under erection in a hydro-electric power station on Po river :—

Runner diameter : 5m. (16ft. 5in.)
Head : 8m. (26ft. 3in.)
Output : 12,800 h.p.
Speed : 93·75 r.p.m.

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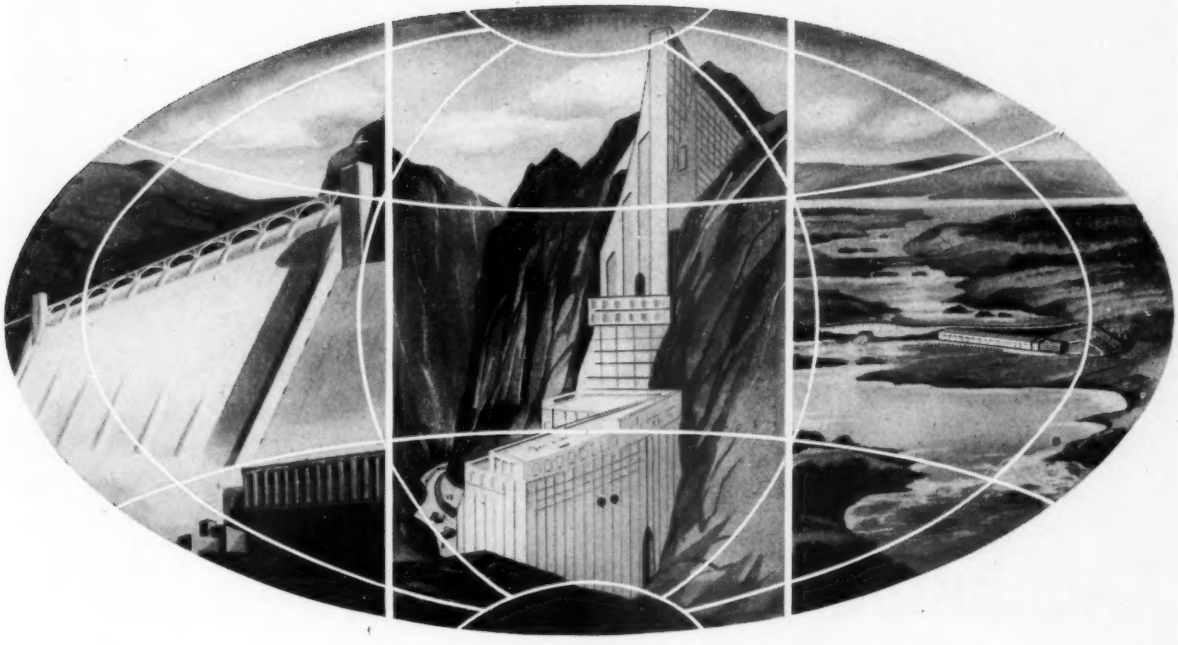

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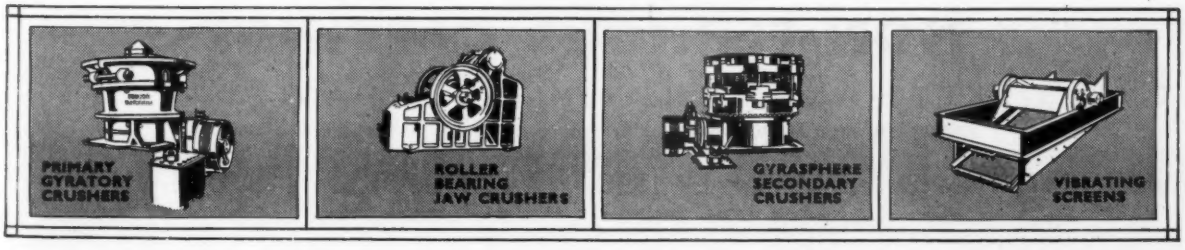

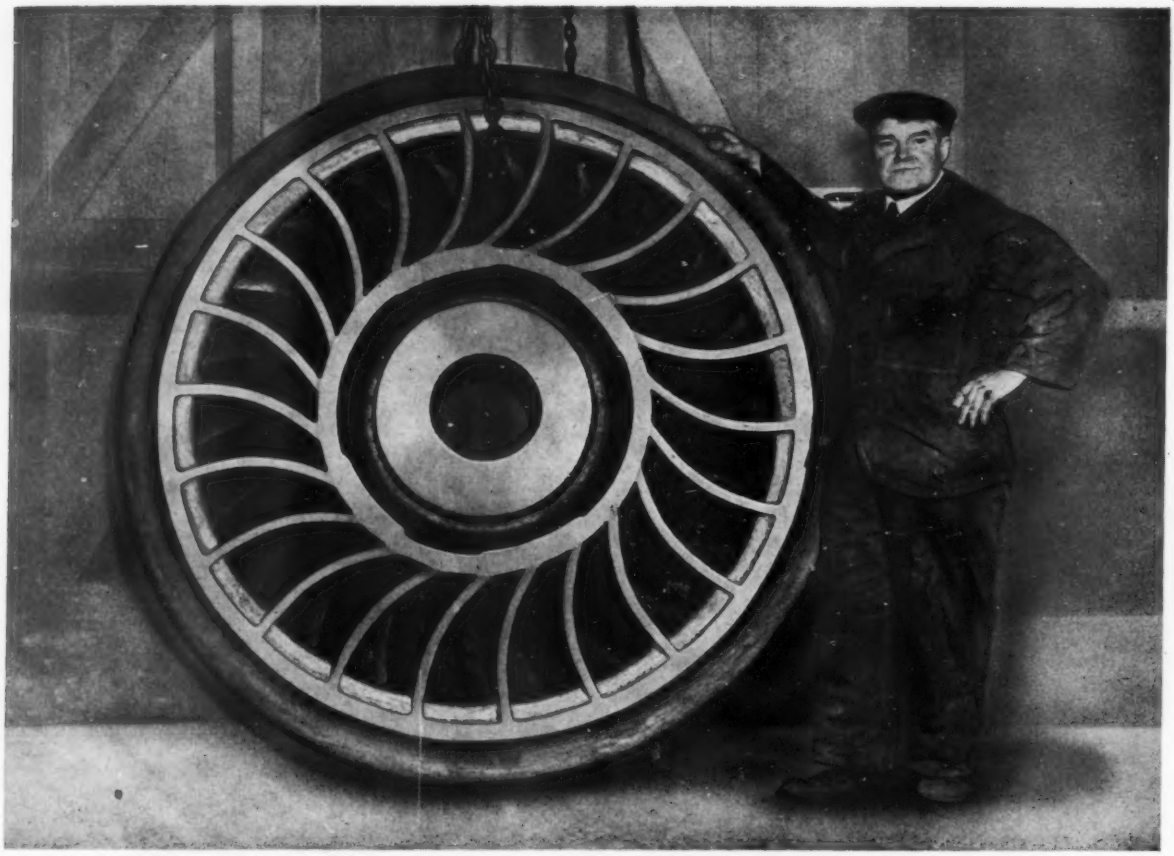

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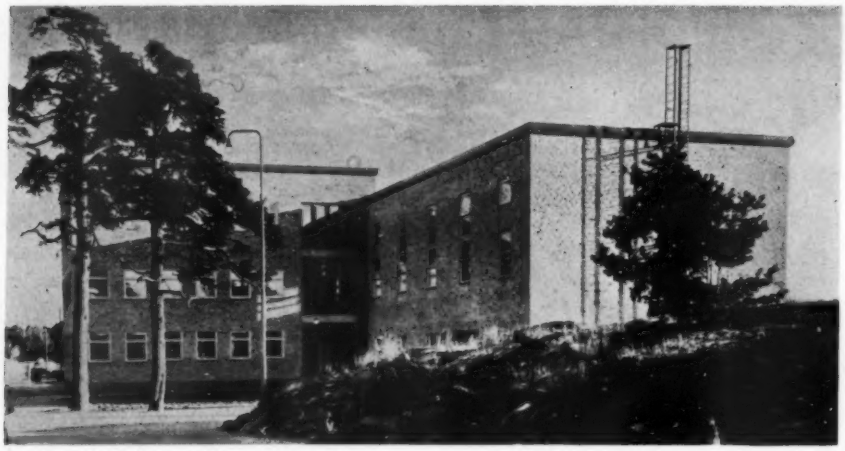

Our new research building at Trollhättan. Water turbine laboratory to the right, containing cavitation test stand, low-head and pump units as well as an aero-dynamic testing device.

NOHAB

WATER TURBINES

and accessories

Our production includes:

GOVERNORS
for automatic and semi-automatic control, also of the

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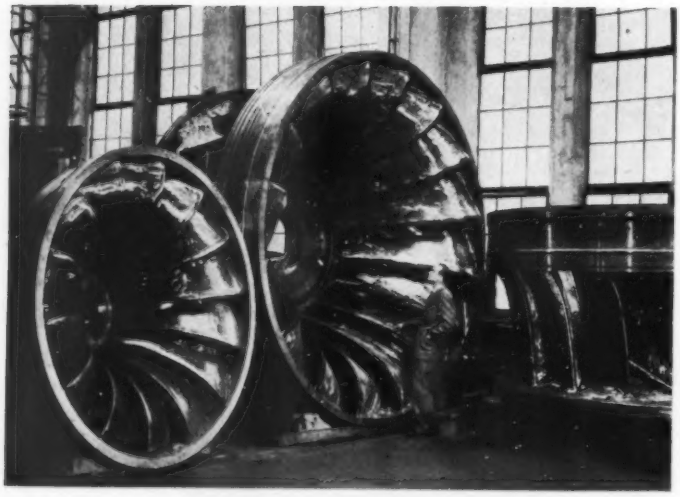

A couple of Francis runners cast in stainless steel

In our modern turbine testing station, also situated at Trollhättan and utilizing a part of the natural fall of the Göta river, model runners having a diameter of 600 mm. are tested.

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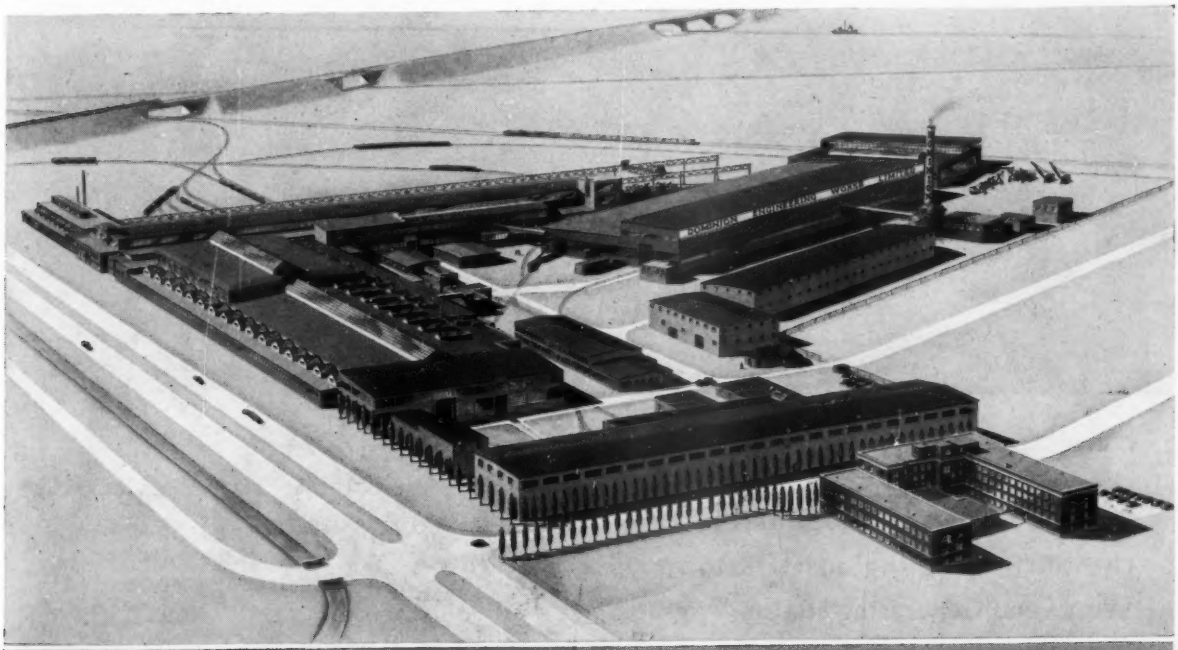
As its contribution to the world-wide development of hydro-electric power, in 1951 alone Dominion Engineering contracted to build, for Canada and abroad, Francis, Propeller and Impulse Type Turbines with a capacity of over 1,800,000 H.P.

The facilities and experience indicated by such a record are at your service anywhere in the world.

Write for General Bulletin No. 201 on Dominion Hydraulic Turbines.

Dominion Engineering Works at Montreal, Canada



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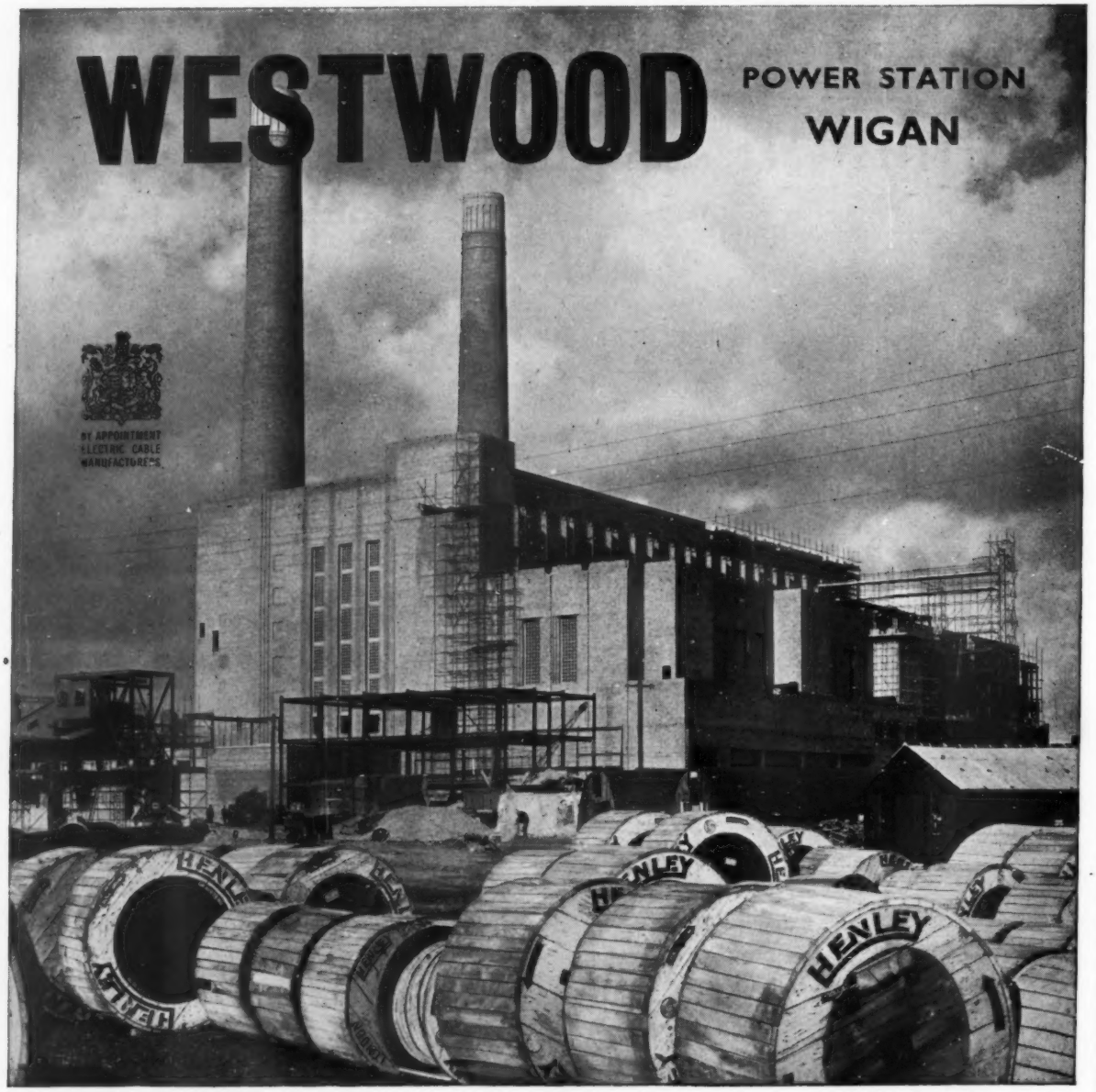

HENLEY'S were responsible for the entire cabling installation at Westwood Generating Station, Wigan.

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Consulting Engineers: Kennedy & Donkin

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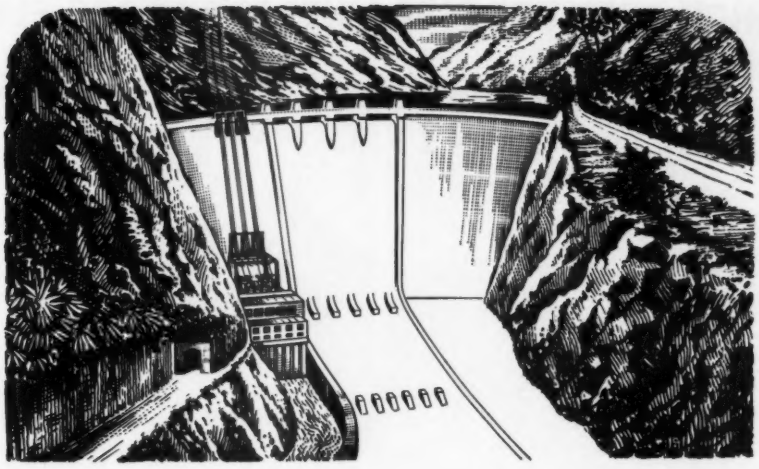

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Top : Artist's impression of the Los Peares Power Station, North West Spain.

Left : Complete assembly (on test in the BTH Works), of one of the three vertical waterwheel-driven alternators (62,400 kV A., 11,000 volts, 3-phase, 50 cycles, 214 r.p.m.) to be installed in the above Power Station.

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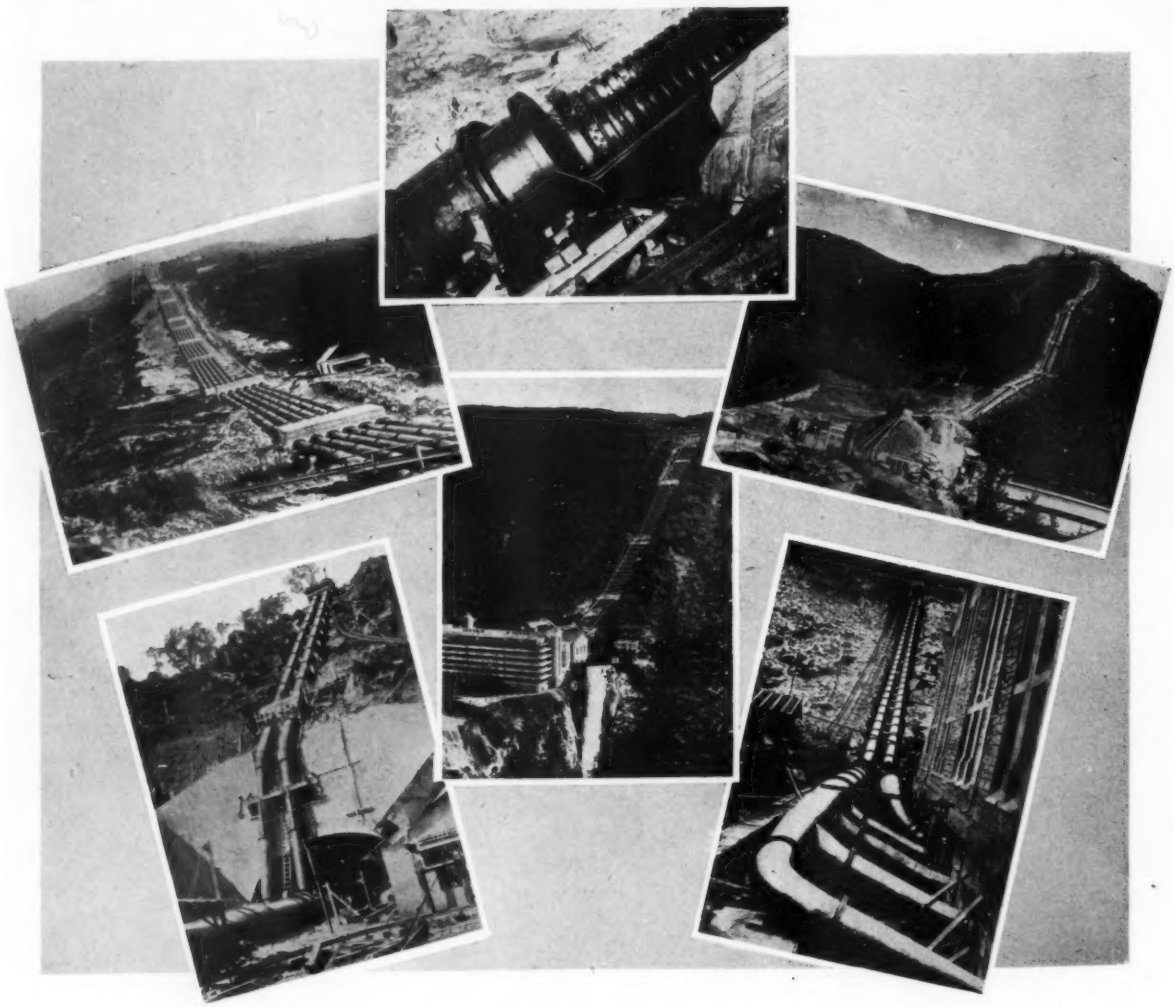

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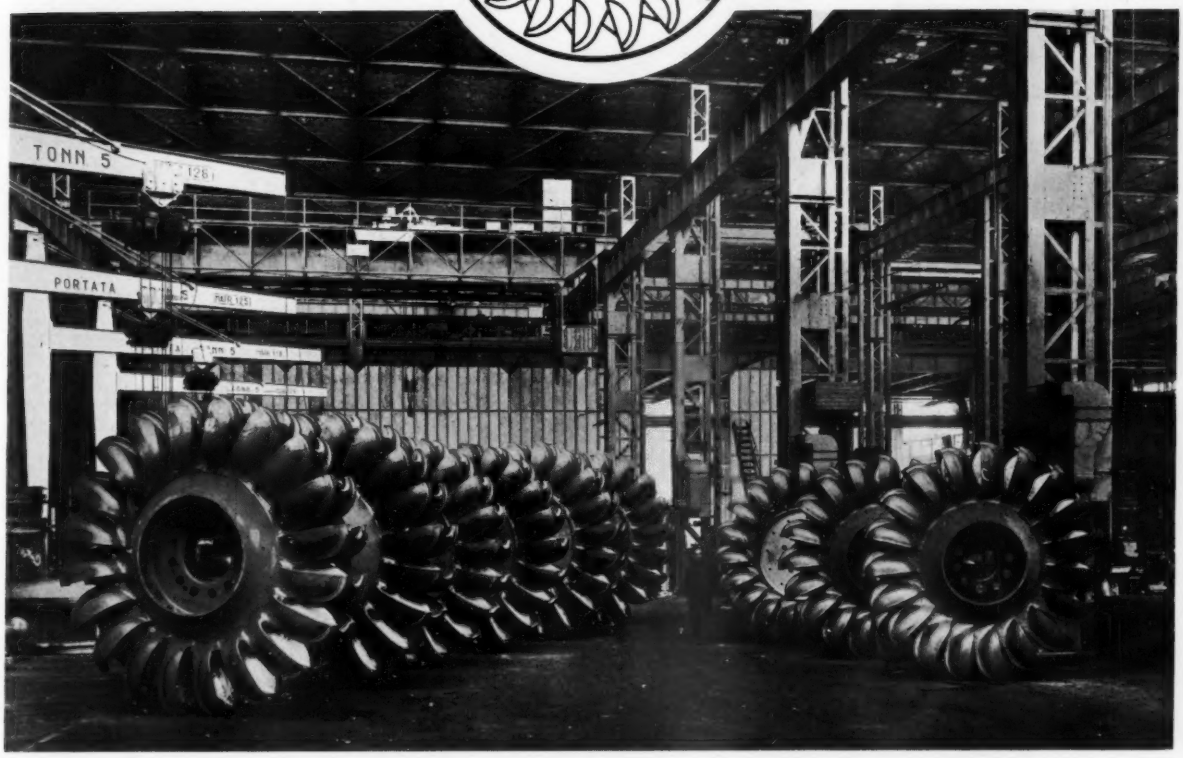

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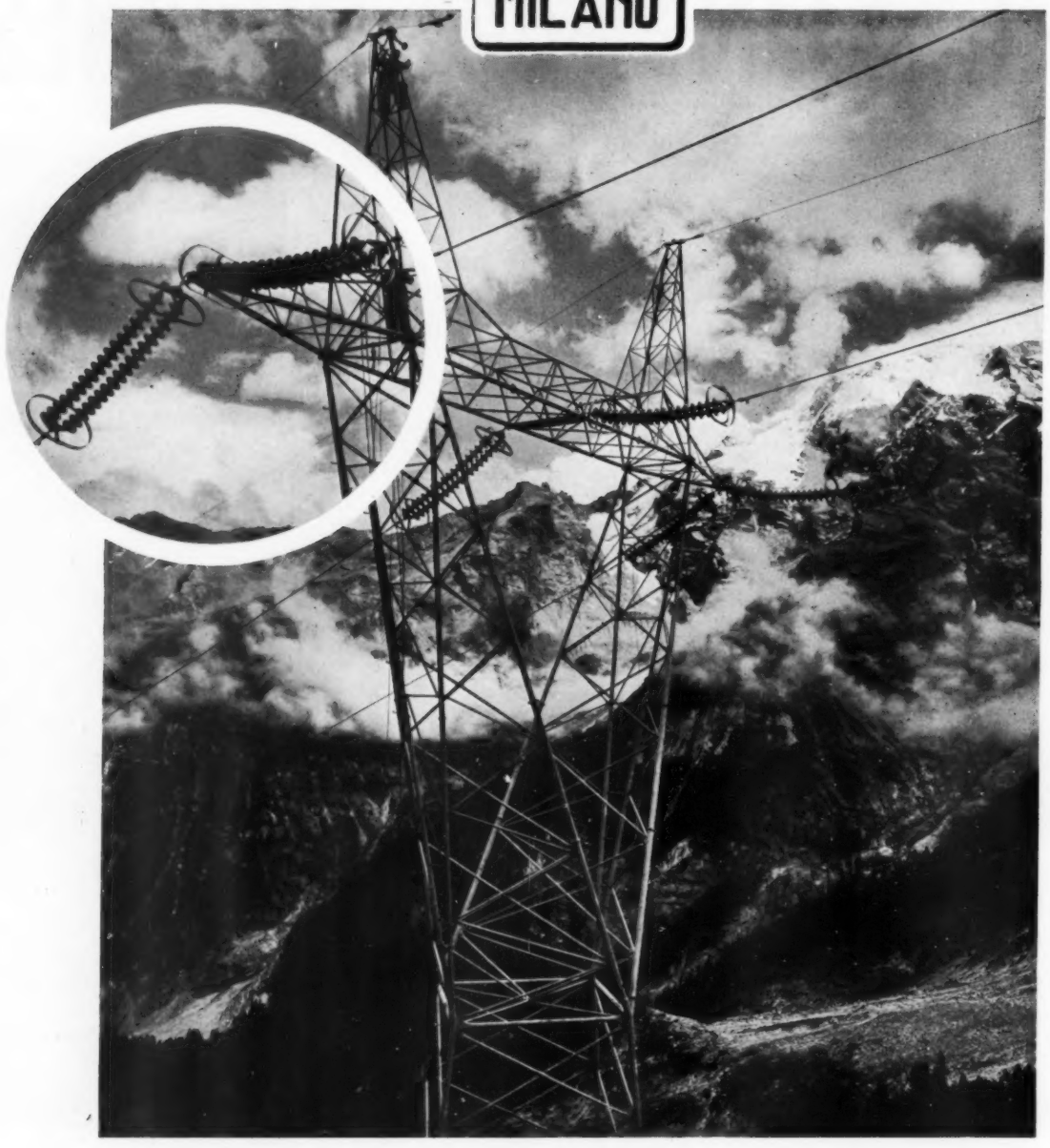

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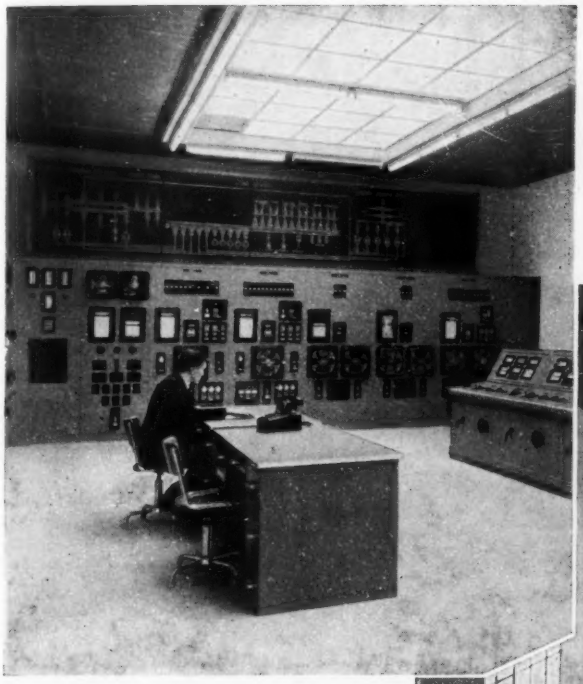
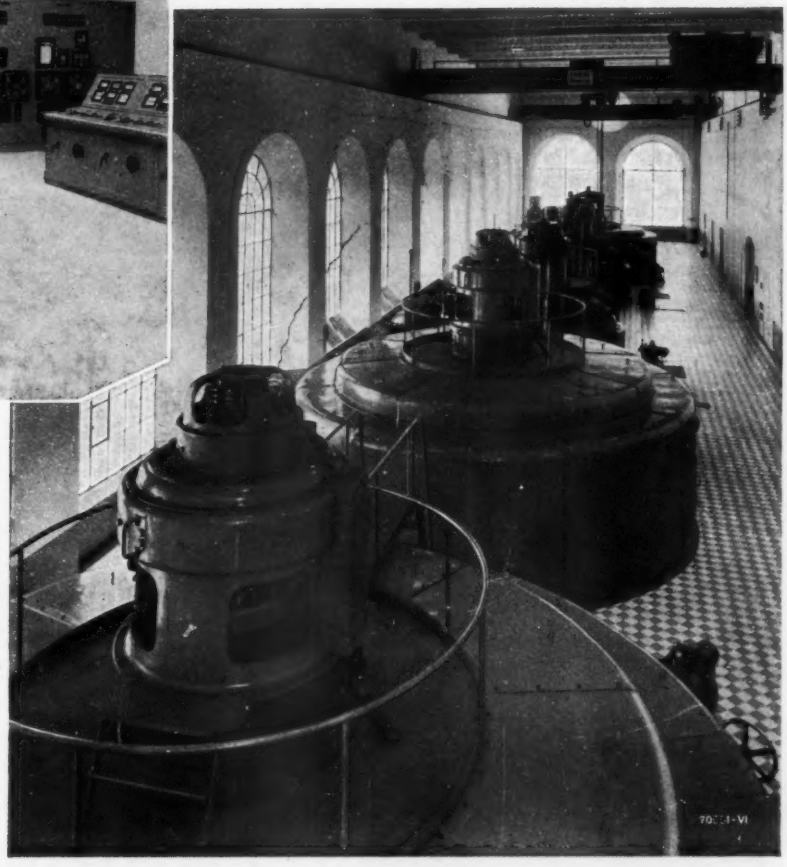


Control room and machine hall at the Rossens - Hauterive power station (Switzerland)



All the alternators in this station, as well as the protective and regulating equipment, were supplied by Brown Boveri

In the foreground two three - phase 20,000 - kVA, 300 - r.p.m. alternators

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Henderson Aerial Cableways have solved the problem of raising, transporting and depositing concrete, shuttering and other materials for the construction of large Dams and Barrages.

Henderson Cableways are being used for the construction of the Dams at Loch Sloy and Glen Shira, North Scotland, Hydro-Electric Board, and various other home and overseas undertakings.

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FOR HYDRO ELECTRIC SCHEMES

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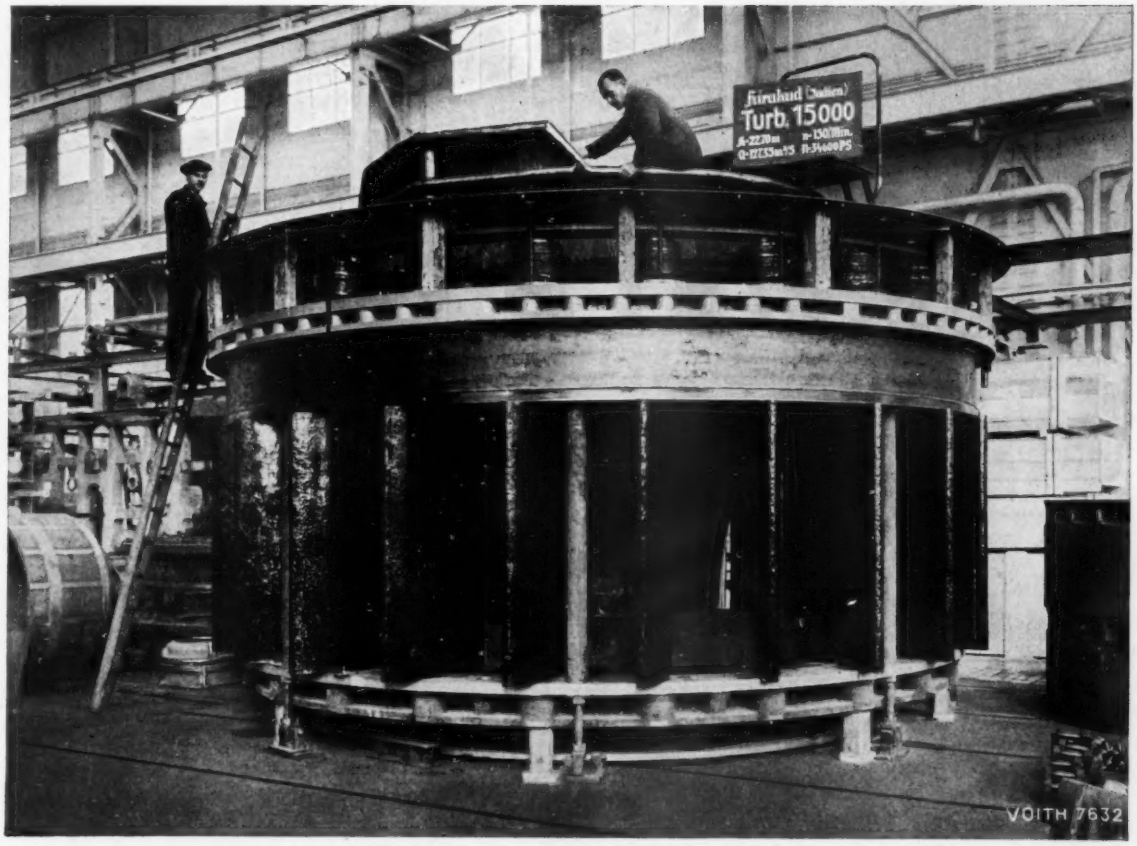
Voith Some representative figures on water turbines

YEAR	NUMBER OF TURBINES	TOTAL OUTPUT IN H.P.
1870	1	100
1889	100	1,000
1901	1,000	135,000
1912	5,000	2,000,000
1927	10,000	6,000,000
1950	15,000	14,750,000
1952	15,300	16,000,000



Workshop assembly of wicket gate for one of two Kaplan-turbines each rated at 34,600 H.P. under a head of 23 m. The turbines have been supplied for a river power station in India.

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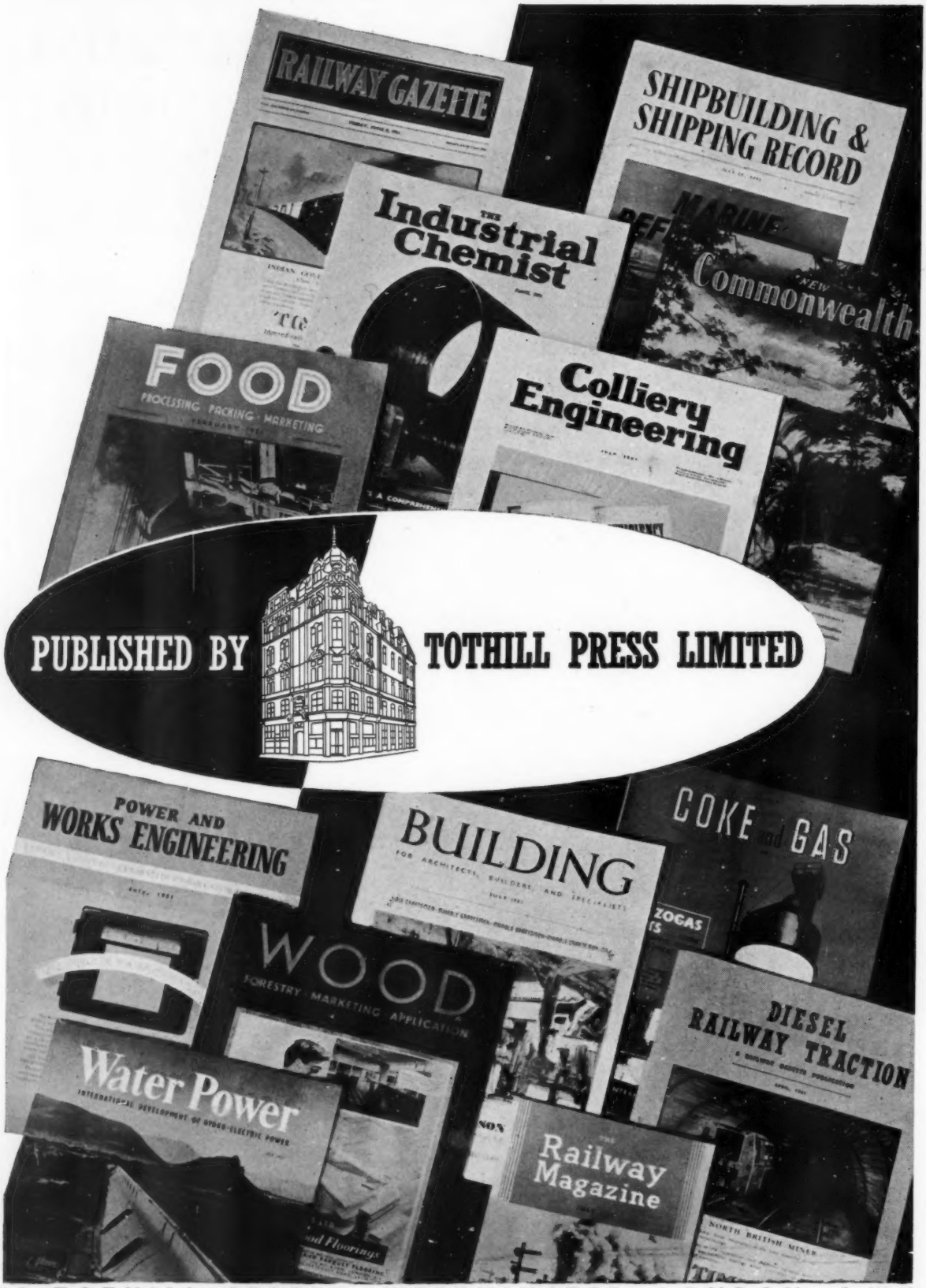

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Boving

The Waitaki power station is at present being extended with two BOVING-FRANCIS turbines. The station will then contain seven main turbines, all but the third and fourth being supplied by BOVING. The fabricated runner for one of these turbines is illustrated.

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Nett head	70 ft.
Output	23,000 b.h.p.
Speed	125 r.p.m.
Type	Vertical BOVING-FRANCIS
Diameter of runner	12.3 ft.

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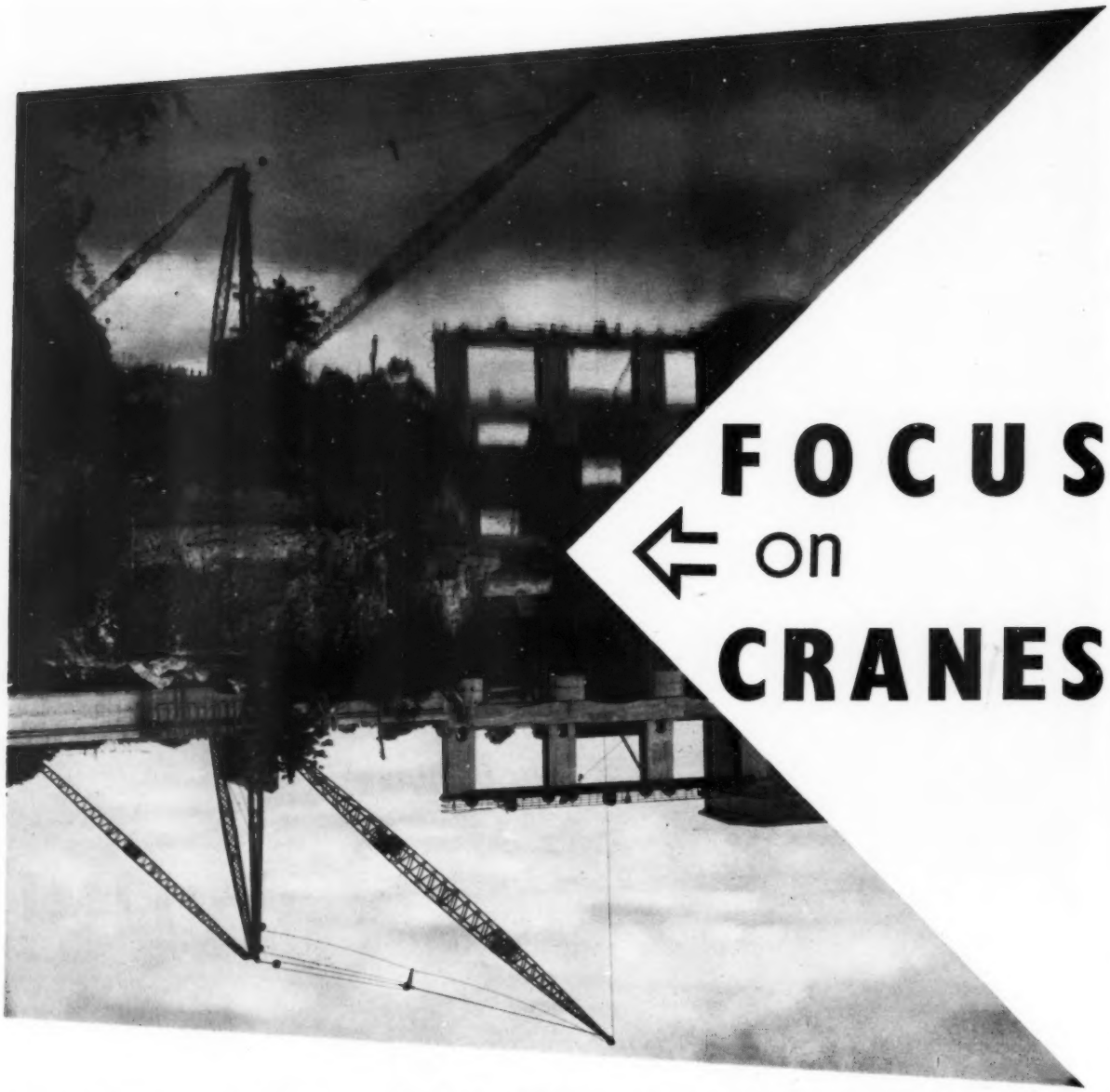

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or any other Butters model: crisp performance and reliability, fitness for purpose and adaptability are the features.

These pictures show two of several derricks which were in use on the construction of the Ballyshannon Hydro-electric Scheme (Main Civil Engineering Contractors: Messrs. Cementation Co. Ltd., Doncaster), a fixed 5-ton model with 130-feet jib, and left, a travelling 5-ton crane with 90-feet jib.

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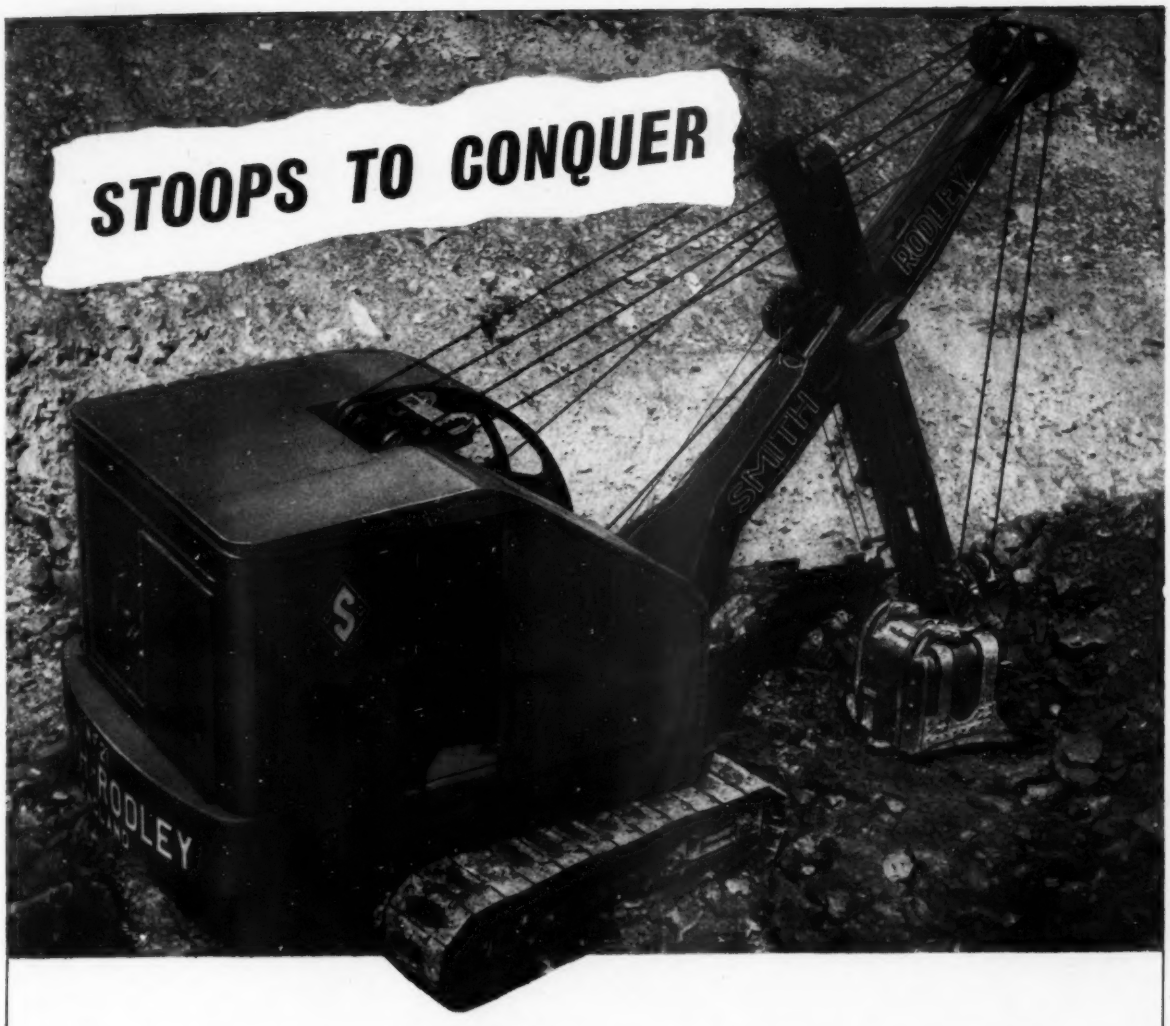
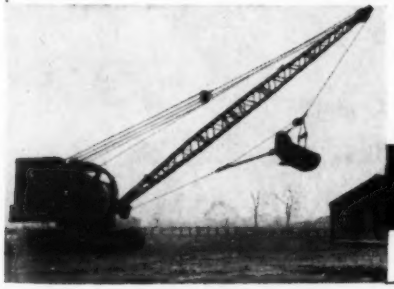


The 'ups and downs' in the life of a Smith '21' add up to a very high level of output. Two main reasons for this are (I) its remarkable sturdiness and simplicity of upkeep with minimum time off for overhaul and (II) the versatility and quick-changeability of its front-end attachments which include: Face Shovel, Dragline, Dragshovel, Skimmer, Crane, Grab Crane and Pile-Driver.



Smiths of Rodley

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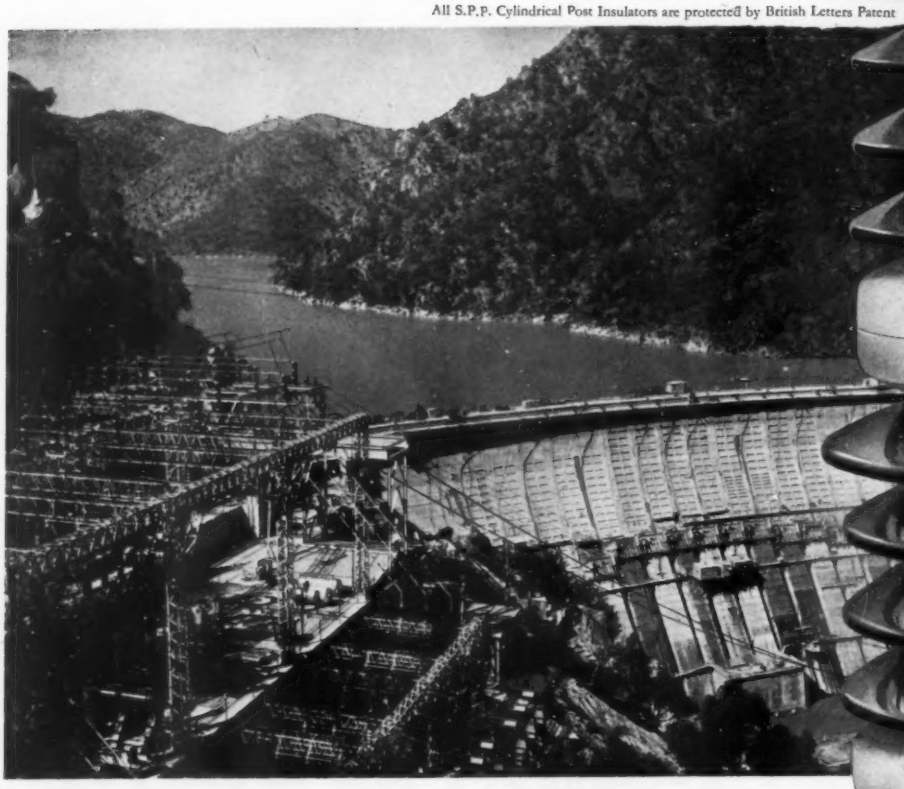
S.P.P. Post Insulators were specified by the New South Wales Public Works Department for Burrinjuck Sub-Station.

All S.P.P. Cylindrical Post Insulators are protected by British Letters Patent



The Burrinjuck 132 kV Switching Station was equipped with Cylindrical Post Insulators type P.703. This is one of many stations on the New South Wales Public Works Department system equipped throughout with S.P.P. Post Insulators for 110 kV and 66 kV.

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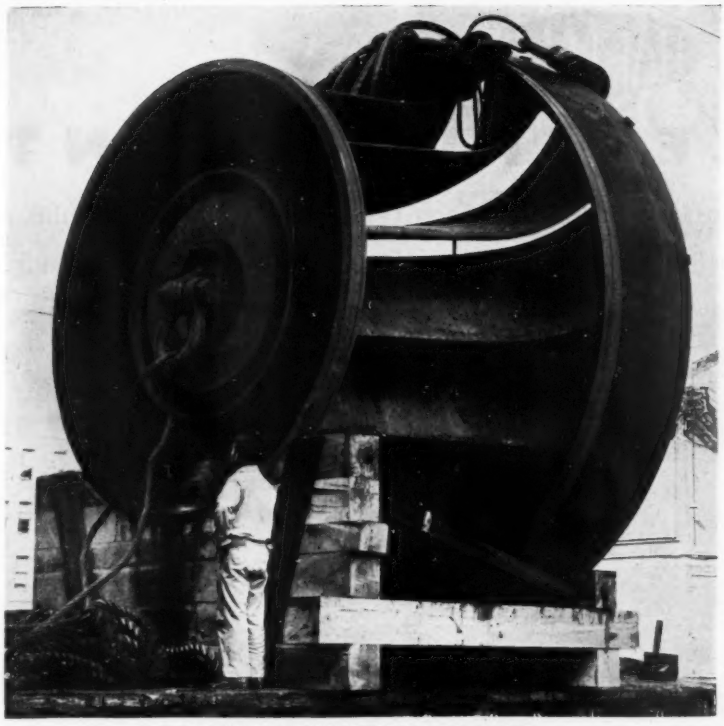

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OVER EIGHT MILLION HORSEPOWER

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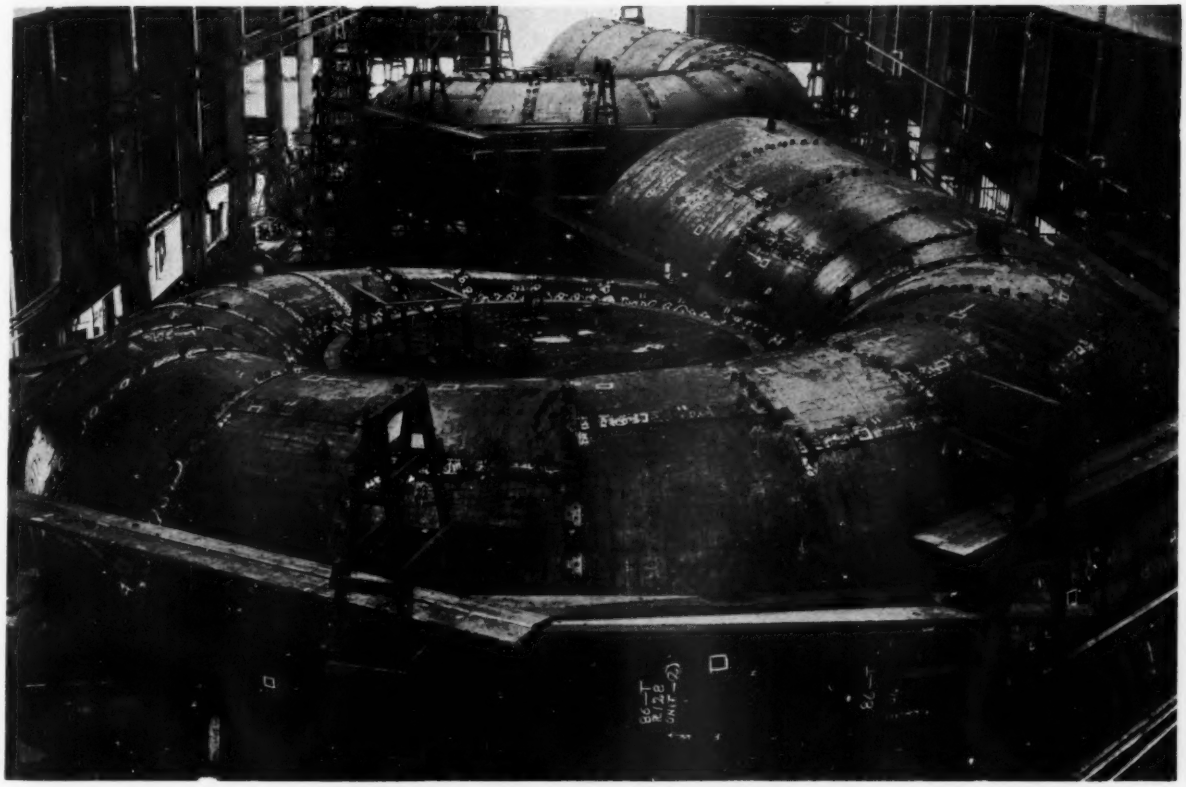

ASSEMBLY OF SPIRAL CASINGS FOR C. J. STRIKE DEVELOPMENT

NEWPORT NEWS
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HARLAND

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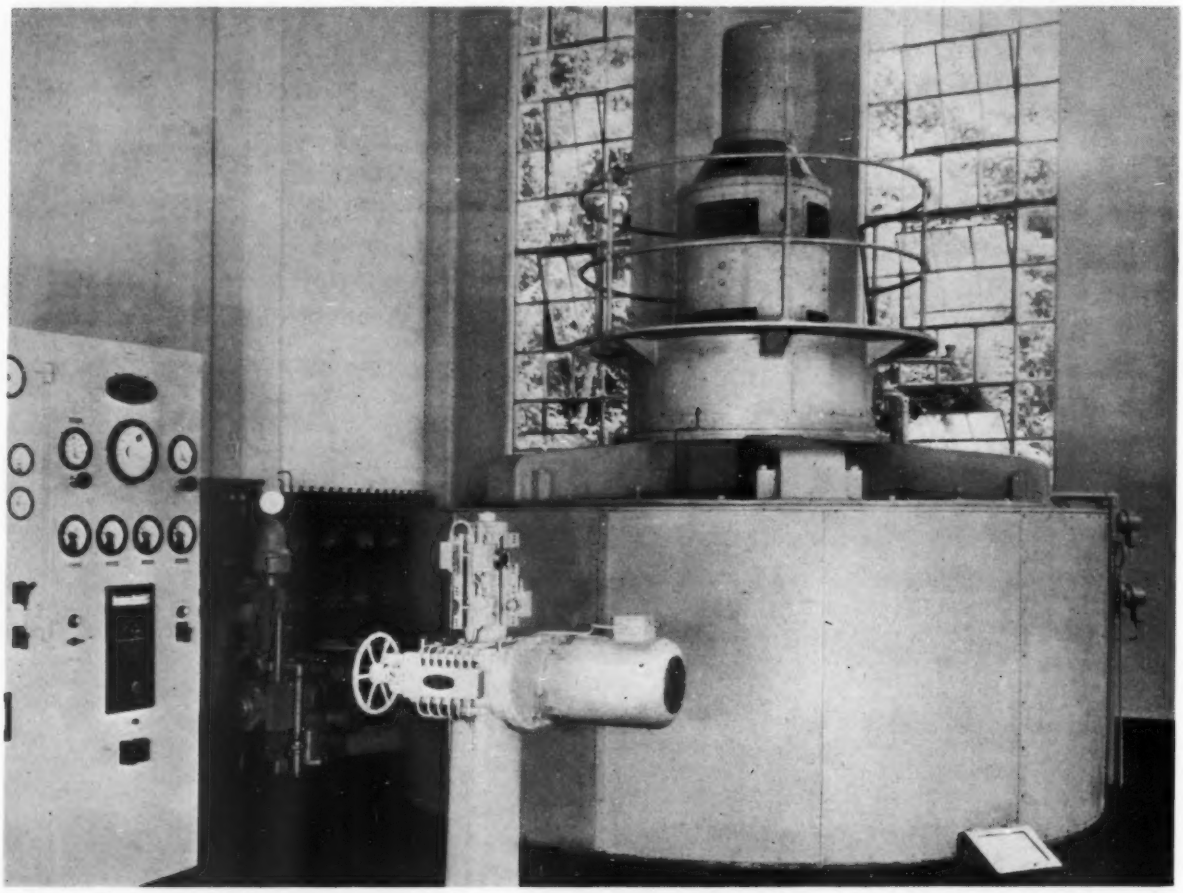
with turbine and generator manufactured in one factory and erected at site under unified control is installed in the Lower White River Generating Station, Jamaica.



General view of alternator, turbine panel, governor and "Rotovalve" control pedestal

A "Harland-Morgan Smith" vertical shaft, Francis type, dual speed water turbine rated at 6700 b.h.p. under 378 ft. head complete with a 36" smooth bore type "Rotovalve" drives this "Harland" vertical shaft, 5,600 kVA, 40/50 cycles, 6.9 kV, 3 phase, A.C. Synchronous generator.

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VOLUME 5 NUMBER 1

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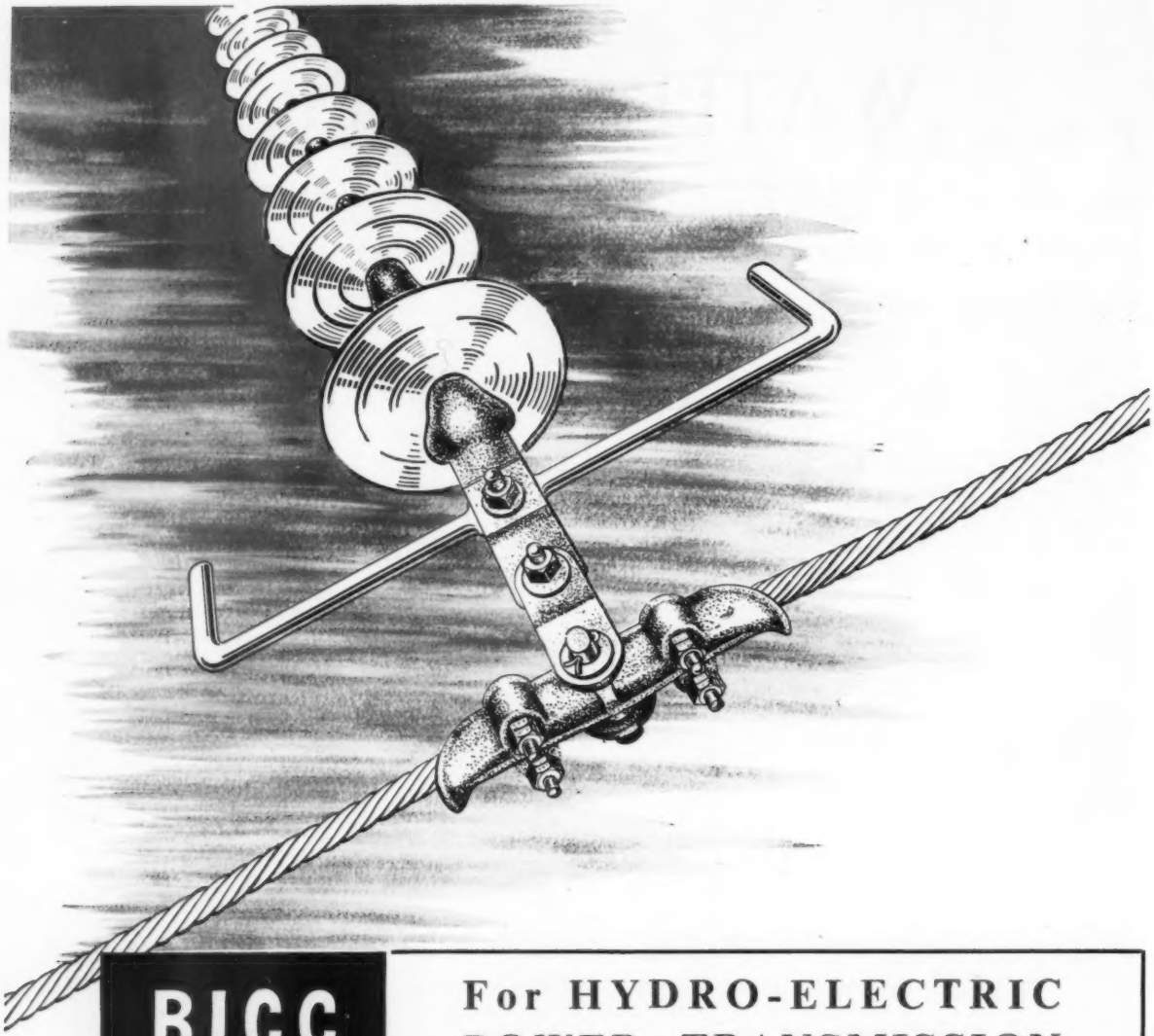

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International Energy Transportation

THE latest number of the Economic Bulletin for Europe* issued by the United Nations discusses at some length the long-range transportation of electricity with a view to international exchanges of power. Substantial differences in the cost of energy generation in one region compared with another might lead it to be supposed that there is a wide range of opportunities for transporting energy from regions of cheap generation to regions where energy is dear. In point of fact, however, as the Bulletin states, these price differences have not been very effective in promoting international trade in electrical current. Instead, the tendency has been for countries with cheap power to increase domestic consumption by developing industries which require large blocks of cheap power; for example, the manufacture of aluminium, calcium carbide and fertilisers. As a result of this concentration on local opportunities, international trade in electricity amounted in 1950 to only 1·5 per cent. of the total output generated. In contrast, 12 per cent. of the coal raised in Europe crossed a frontier before it was consumed.

This is understandable enough when it is recalled that hitherto the cost of hauling coal has been cheaper than the cost of transmitting an equivalent amount of electrical energy. But the rising price of coal is narrowing the margin, and this tendency is being intensified by the general increase in transport costs, particularly railway charges.

A further difficulty hinges on the utilisation factor; obviously it is cheaper to transmit a steady flow of current than a highly fluctuating one, but the transport of coal is not adversely affected in this way. Moreover, a supreme advantage of coal is that it constitutes a compact form of energy that can be stored. This has suggested to the compilers of the Bulletin that the advantages of combining both forms of transport should be closely examined — the electricity transmission lines carrying the steady base load, with the thermal plants, working on stocked coal, providing the peaks.

But cost relationships of this kind are always changing; it may be that some technical innovation will cheapen the transport of electricity or it may be that some improvement in the economy of thermal plants will require less coal to be used for a given output of electricity and will entail the transport of reduced quantities of fuel. What is perhaps significant in this matter is that in England, where there has been some controversy as to whether London should be provided with electricity generated in Thames-side plants with coal brought from the Midlands by rail, or with current generated at pithead stations and brought over high-tension transmission lines, the issue has been resolved in favour of transmitting the current. But in this instance the economics of the situation have been heavily influenced by the fact that low-grade coal is to be used for the power generation, the coal characteristics being such that cleaning would be too expensive and rail transport equally prohibitive because of the high content of incombustible material which would be of negative value when it had been brought to London.

Coal in general, however, is showing no tendency to become either cheaper or more plentiful. On the other hand there are immense resources of water power in such countries as Norway and Jugoslavia, in which electricity could be generated so cheaply as to offset fairly high transmission costs. In Norway the abundance of water power enables electricity to be sold at about $2 per MWh, whereas in neighbouring Denmark the cost of thermally generated electricity is about $20 per MWh. Negotiations for a transfer of electric power have so far failed, however, the Bulletin stating a major obstacle to exist "in the strong popular aversion in Norway to exporting the one important natural resource of the country, even though meanwhile the effective exploitation of that resource is held back by lack of capital . . . ."

In the case of Jugoslavia the coastal section of the

* Economic Bulletin for Europe, Vol. 4, No. 3. H.M. Stationery Office P.O. Box 569, London. Price 3s. 9d.

Dinaric Alps in the region of the Austrian and Italian frontiers is stated to offer very favourable sites for water power plants and the costs of construction are estimated to be very low. Also, in contrast to the Swiss Alpine region, the winter flow of water is particularly plentiful. It is consequently concluded that the export of electrical energy could very advantageously be made to Austria and Italy.

Of more immediate interest, perhaps, are the experiments which the United Kingdom and France have initiated with a view to constructing and operating a cable that will effectively connect the distribution grids of both countries, with a view to relieving peak-load problems. It is proposed that this cable should carry 100 MW, which seems a little modest when measured against the British peak of 13,000 MW. Apart, however, from the economics of this interchange of current, the technical problems involved are of unusual interest and complexity and once they are satisfactorily solved many possibilities may be opened up.

Rural Electrification

THE Electric Power Committee of the United Nations Economic Commission for Europe (ECE) has for some time been preoccupied with problems of rural electrification. A series of meetings now under way offer promising results towards helping to solve these problems. In particular the Committee are seeking to discover the best methods for the electrification of various kinds of agricultural regions. Towards this end, the Committee called for a study which would include four related parts—production; distribution and transmission; utilisation; and economic, financial and administrative questions. It also suggested methods for realising the study.

A preparatory stage consisted in the collection of reports, based on a common plan, indicating the results of experience in individual countries. Fourteen monographs have now been received by the ECE Secretariat to date. The drafting of this study has been assigned to experts—Mr. C. A. Cameron-Brown, Agricultural Electrification Adviser of the British Electricity Authority; Mr. M. A. Dussarte, Honorary Controller-General of Electricity of France; Mr. F. Ringwald, Director of Motive Power in Central Switzerland; and Mr. T. R. A. Strand, Director of the Regional Administration of Alvkarleby, Sweden—who will be drafting a report in due course.

Developments Foreshadowed in South America

ON the recommendation of the Brazil — United States Commission, the World Bank has authorised the loan of 25 million dollars to a state-owned enterprise in Rio Grande do Sul, to finance imports of equipment for four hydro-electric and four thermal power stations designed to raise the plant capacity by 137,200 kW. The loan, which will be used to purchase foreign currency, is for 25 years.

Eight other projects call for loans totalling about 60 million dollars (U.S.) have been approved by the Commission and now await a decision by the banks. Four of the proposed loans are to cover imports of power station equipment, namely: 7·7 million dollars for the 60,000 kW station at the Salte Falls; 5·3 million dollars for the 36·2 kW central station now being built by the Comphania Electrica do Alto Rio Grande at Ututinga to assist development of a rich mineral and manufacturing zone in Minas Geraes; 8·5 million dollars to the Cia Hydro-Electrica do Sao Francisco to install a third 60,000 kW generator and 1·47 million U.S. dollars to the Cia Nacional de Electricade..

In August the Parana Government submitted plans for a hydro-electric station at Gotia, a coastal zone, and Curityba, the capital, both schemes having been repeatedly delayed and further economic progress is retarded by inadequate power supplies. Installed capacity, public and private, amounts to only 35 kW, some 5,000 kW short of requirements, although hydro-electric potential within the State is estimated at 4 million horse-power. Cotia power station will satisfy immediate needs and supply power to electrify the Parana-Santa Catarina Railway, for which another loan has been requested.

Among other projects, not dependent on the Brazil Commission, the Sao Franciso Valley Commission has signed a contract with the Minas Geraes Government for supplementary works for the central station at Fecho do Funil. A dam will be built on the Para River, near Ca mo do Cajura, to regulate the flow of water, raise the capacity of the Gafanhoto Station and facilitate work on the main station.

Ontario Hydro

THE 1951 Report of the Hydro-Electric Power Commission of Ontario records a further period of accelerated expansion. The total amount of primary energy supplied to municipal electric utilities during the year advanced 11·6 per cent. over that of the calendar year 1950, while direct supplies to industrial customers and to rural power districts increased 16·8 and 16·4 per cent. respectively. The year saw the placing in service of the eighth and final unit at Des Joachims and the remaining six units at Chenaux. Ontario Hydro also brought into operation the two largest fuel-electric generating stations in Canada. This brought to eight the number of fuel-electric stations operated by the Commission, while the number of its hydro-electric generating stations in operation was 63. Water conditions were exceptionally good, particularly in the latter half of the year.

As a result of increased generating capacity, offset in part by a reduction in the amount of power available from purchased power sources, the combined dependable peak capacity of all sources rose from 2,730,300 kW in 1950 to 2,941,750 kW in December 1951, an increase of 211,450 kW or 7·7 per cent. The Commission's generating stations produced a net output of 14,025,616,458 kWh during the year. In addition, the Commission purchased under its regular, temporary and short-term power agreements, 4,785,835,598 kWh making a total of 18,811,452,056 kWh generated and purchased. The record net output of all sources for 1951 exceeded that of the calendar year 1950 by 18·5 per cent.

The assets of the Commission at December 31, 1951, totalled $1,036,029,755 after deducting $116,945,856 of accumulated depreciation and $63,015,165, the provincial grant-in-aid of rural construction. This represents a substantial increase in assets, of which

the major item is capital expenditure. This capital expenditure amounted to $164,617,930, reflecting the continuation of the Commission's expansion programme. Of the capital expenditure in 1951, 51 per cent. was on new generation, some of which came into service in 1951, but a large portion of which is scheduled for service in the years 1952 to 1957. In addition to this capital expenditure, an amount of $39,456,723 was spent on frequency standardisation. This includes $6,834,590 which was invested in material and equipment for future standardisation. This amount, when added to that already similarly invested, represents an expenditure at December 13, 1951, of $26,746,651, all of which is applicable to future standardisation projects.

Electricity Supply in Eire

IN its annual report for the year ended March 31, 1952, the Electricity Supply Board of Eire states that the total output for the year was 1,029 million kWh, to which hydro stations contributed 456 million kWh. This represents an increase in output of 6·25 per cent. On the other hand, the demand in the earlier part of the year was 30 per cent. above that obtaining a twelvemonth previously, and rationing had to be reintroduced from May to September, particularly as water storage had been drawn down much below normal. The flows were considerably below the average from May to October, but recovered to more than normal during the winter months. The average flow for the year was approximately equal to the long-term mean inflow in the case of the Shannon catchment, but below the mean for the Erne and Liffey catchments. Investigations were in hand for the development of the Avonmore River, Co. Wicklow, and the River Clady, Co. Donegal, and data were being collected with a view to the possible development of other sites.

North Wales "Threat"

THE annual report of the National Trust for Places of Historic Interest or Natural Beauty mentions "a further threat not only to Trust property but to one of the recently constituted National Parks in the North Wales Hydro-Electric Schemes."

"The Bill promoted by the British Electricity Authority in the 1951-52 session has now been enacted. It gives preliminary sanction to the extension of existing schemes at Dolgarrog and Maentwrog. The Trust property of Dolymelynllyn will be affected by the latter, since the River Eden, which joins the River Mawddach on the borders of the estate, will be much reduced in flow.

"Important safeguards for the protection of the scenery were suggested in the House of Commons and have been included in the Act. Not only will the approval of the Local Planning Authority now have to be obtained, but the Royal Fine Art Commission and the National Parks Commission will have to be consulted. There is also a recommendation from the Minister that a landscape consultant be employed. There is no obligation upon the Electricity Authority to act upon any advice they receive in this way, but it is to be hoped that they will welcome such advice. If these pioneer schemes can be carried through in such a way as not to damage the beauty of the countryside the Electricity Authority will have set an important precedent.

"Application by the British Electricity Authority for permission to start other schemes, more threatening to Trust property and to the newly constituted Snowdonia National Park, will be awaited with considerable apprehension. In view of the continuing danger that threatens both the nation's finest buildings and its open spaces, the Council impress upon members their responsibility for constant vigilance and their duty, as far as lies in their power, to keep local opinion awake and fully imformed. Acting as an organisation the Trust can do much; but representations from Head Office are no substitute for the local and individual activity of 33,000 members.

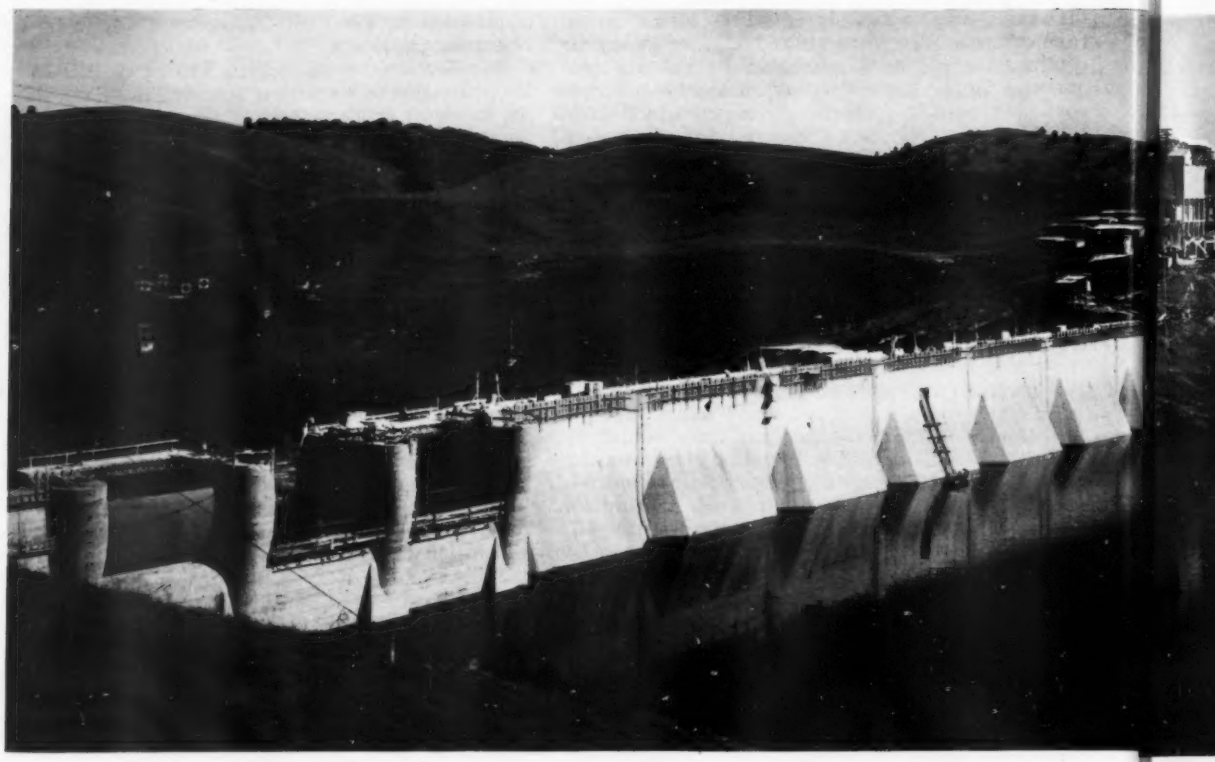
Cowal Scheme Extension

THE North of Scotland Hydro-Electric Board have decided to extend their Cowal hydro-electric scheme to meet the rapid increase in demand for electricity in the surrounding district. This project, No. 69, consists of a series of aqueducts and short tunnels which will collect, at a level of about 500 ft. O.D., the headwaters of a number of small streams at present flowing into the head of Loch Riddon. The water will be diverted through the hill between Loch Riddon and Loch Striven to an aqueduct and thence through a pipe to the existing power station on the shores of Loch Striven. Where the pipe crosses the flat marsh land at the head of Loch Striven it will be buried. The original Cowal hydro-electric scheme was opened in September 1951 and has an estimated annual output of 14 million kWh; the extension will increase this output by a further 4·6 million kWh per annum.

Madras Demand

MADRAS STATE demand for electricity is rising steadily and is far ahead of supply possibilities. Dissatisfaction has been expressed by both agricultural and industrial interests and as schemes under construction will only barely suffice to meet the demand, new projects will have to be undertaken. In regard to rural electricity, Madras probably leads the rest of India. Installed capacity of generating plant in the State was about 160 MW at the end of the war. In 1945 a number of major schemes were put in hand to bring the capacity up to 180 MW and so far an additional 34 MW of plant has been commissioned. Other projects will be completed in 1954, including the Machkund hydro-electric projects and will make an additional 51 MW available. The rest of the programme includes the remaining two of the three 12 MW sets in Moyas, one of which was brought into operation in April this year; the Tungabhadra hydro-electric station; and extensions to existing stations at Pykara, Madras and Madura.

In the Madras area the shortages will exist even after two 15 MW sets are commissioned. The Machkund project will have to supplement other systems in Madras and further demands will necessitate undertaking the second stage of the Machkund scheme to provide additional generating plant. The position will be serious until 1955-56 when completion of the first stage of the Tungabhadra hydro-electric scheme is expected to provide an additional 26·4 MW.



The Bau Muggeris Dam

This dam, in the Upper Flumendosa Basin, Sardinia, is a cellular gravity structure, and in this first part is described with reference to geographical and geological conditions on site, together with the methods followed in its design and construction.

By DR. ING. CLAUDIO MARCELLO

AT the end of 1947 the " Società Idroelettrica Alto Flumendosa " resumed, after it had been discontinued in July 1943, the construction of three hydro-electric projects planned for the development of the upper reaches of the River Flumendosa, from El.800 m. to the Tortolì plain at about El.68 m. above sea level, in the North-East of Sardinia. The projects had been carried out to the extent of about 50 per cent. in the first stage of construction and were finished in little more than two years after the work was recommenced.

This group of plants, according to the studies carried out by the company, is expected to ensure an output of 130 million kWh per year. In consequence, the total output capacity of the Sardinian electric system which amounted to 280 million kWh in 1948, will be increased by about 50 per cent., reaching a total of about 410 million kWh. Moreover, the installed capacity of the existing generating plants, amounting to 90,000 kW in 1948, will also be increased by about the same rate; 40 per cent. of this capacity is installed at thermal stations and the remainder subdivided between the two hydro-electric plants of Tirso and Coghinas.*

The Flumendosa stream, originating from the highest peak of the Sardinian mountains, the Gennargentu (1,843 m. a.s.l.) runs through the south-east portion of the island, streaming from east to west in the first stretch and then turning to the south to flow into the sea on the Tyrrhenian coast. The scheme proposed in general outline by Ing. A. Omodeo and determined dimensionally and structurally by Ing. Velio Princivalle, was based on the

* Both these plants were designed by Ing. A. Omodeo and were provided with reservoirs storing a total of approximately 620 million cu. m. Owing to their moderate altitude the reservoirs can store little more than 50 million kWh.

diversion of the headwaters at an elevation of about 800 m. from the upper Flumendosa basin into the Sa Teula—an irrelevant stream flowing into the sea at Arbatax. This scheme, which in geological opinion would restore the region to its original hydrographical condition, allows the utilisation of the available fall (more than 700 m.) by means of three hydro-electric plants, connected by an important system of tunnels driven through the mountains flanking the Flumendosa basin on the east side. A schematic plan and profile of the three plants are given respectively in Figs. 2 and 3. The system includes a reservoir with an effective storage capacity of 58 million cu. m., having a high water level at El.800 created by a 60 m. high dam built at Bau Muggeris. This reservoir drains a basin having a natural catchment area of 62 sq. km., together with the inflow from a 118 sq. km. catchment diverted through the Bau Mela and Bau Mandara intakes, the water from the two latter basins reaching the reservoir through two tunnels having a total length of 2,500 m.

The run-off controlled by the Bau Muggeris reser-

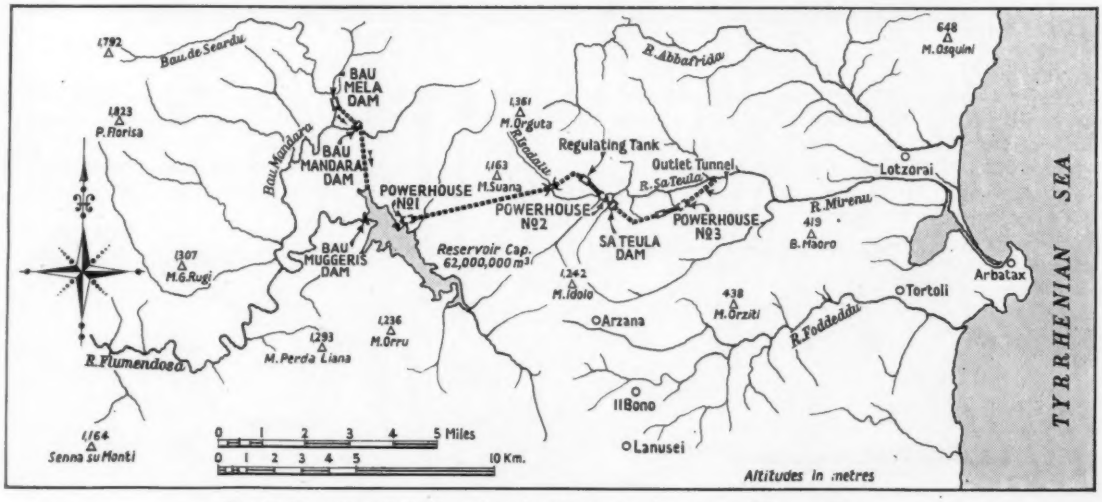


Fig. 2. Layout of hydro-electric plants in the upper Flumendosa

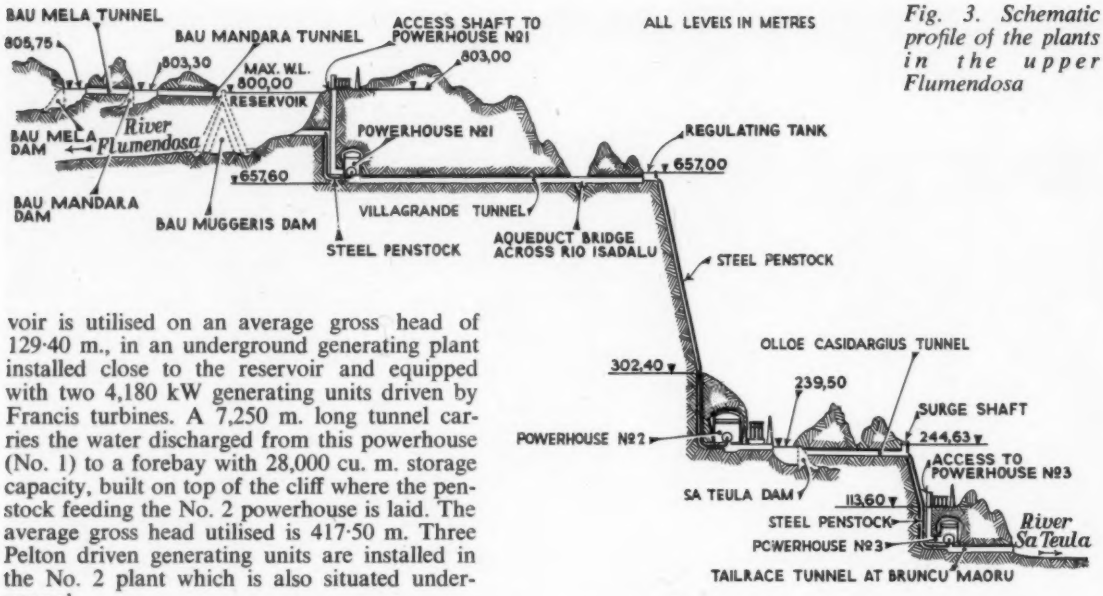


Fig. 3. Schematic profile of the plants in the upper Flumendosa

voir is utilised on an average gross head of 129·40 m., in an underground generating plant installed close to the reservoir and equipped with two 4,180 kW generating units driven by Francis turbines. A 7,250 m. long tunnel carries the water discharged from this powerhouse (No. 1) to a forebay with 28,000 cu. m. storage capacity, built on top of the cliff where the penstock feeding the No. 2 powerhouse is laid. The average gross head utilised is 417·50 m. Three Pelton driven generating units are installed in the No. 2 plant which is also situated underground.

Plant No. 3 utilises the tailwater of Plant No. 2 and the run-off of the small stream Sa Teula, by means of two Francis driven generating units having a combined rating of 10,040 kW. The fall is 171 m. and the tailwater is available for irrigating the Tortolì plain at an elevation of 68 m. All the structures have been designed for a maximum flow of 7 cu. m. per sec.

As stated, the Flumendosa system is expected to ensure an average yearly output of about 130 million kWh, of which 80 million are stored in the Bau Muggeris reservoir. This reservoir, with its 58 million cu. m. pondage at El.800, is the fundamental resource of the whole system, which has a total installed capacity of 45,865 kW.

The hydrologic features of river discharge in Sar-

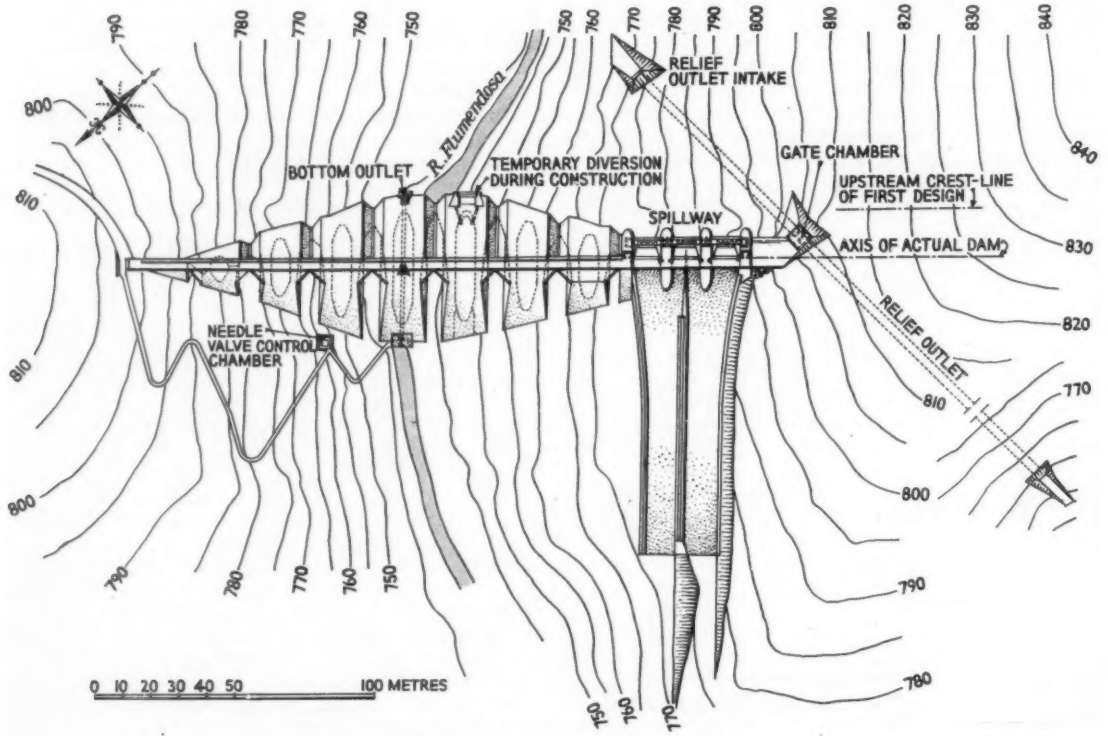


Fig. 4. Plan of the site, Bau Muggeris dam

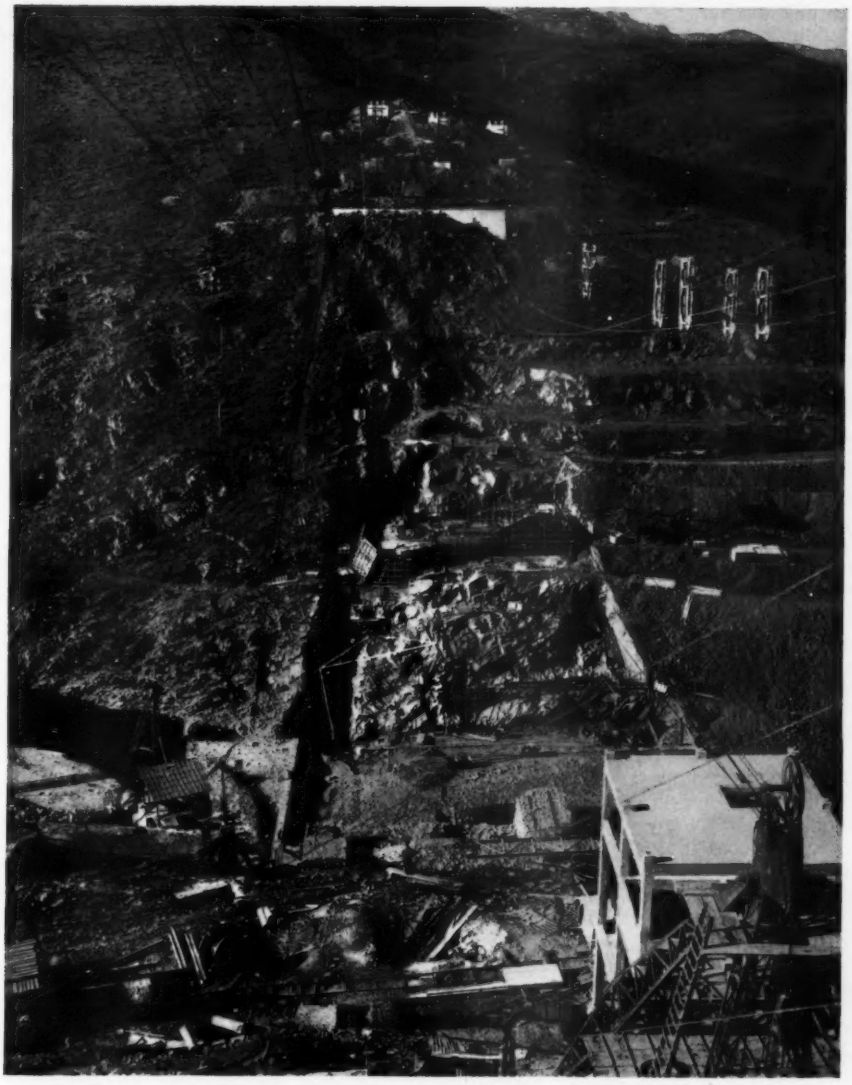


Fig. 5. Foundations of dam, left bank, showing earlier concrete foundations

dinia depend chiefly on the fact that the greatest portion of the yearly rainfall is concentrated during the winter period (November to March). In the headwater area of the Flumendosa the average yearly value of rainfall ranges from about 1,000 mm. but may vary between very wide limits from year to year. In the thirteen-year period from 1923 to 1935 the variations ranged from a maximum of 1,474 mm. in 1930 to a minimum of 624 mm. in 1932 with an average of 952 mm.

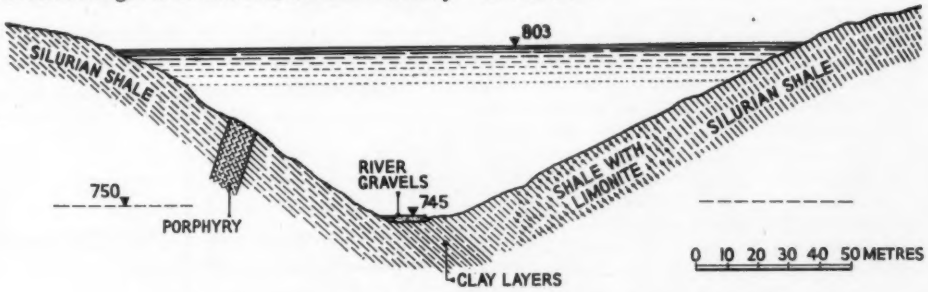


Fig. 6. Geological profile along the axis of Bau Muggeris dam

The average unit discharge of the upper Flumendosa basin is about 20 litres per sec. per sq. km. Sudden and important floods are usual in this area owing to the exceptional intensity of rainfall, the prevailing imperviousness of the catchment area and its peculiar topographical features, and to the very small proportion covered by woods and cultivated land. A flood of 33 cu. m. per sec. per sq. km. was recorded in 1940 in the valley of the Bau Mandara, one of the tributaries of the Flumendosa basin, covering an area of 21 sq. km. On the same date 62 sq. km. in the region of the Bau Muggeris reservoir was flooded by the Sicca d'Erba tributary. The exceptional peak of 15,240 cu. m. per sec. per sq. km. was recorded in this flood.

On the basis of studies made on the Omodeo and Coghinas lakes, evaporation from the Bau Muggeris reservoir is expected to be about 2,000 mm. per year.

Geology

The Bau Muggeris reservoir area, like most of the Ogliastra region, is chiefly formed of Silurian schists which form a blanket of clayey phillite lying on a huge granite mass. Crests of red porphyrite rock outcrop from the often uncovered granite and form long straight parallel lines, the entire mass having been fractured by severe tectonic pressure. The plan of the dam site and a geological cross section of the valley along the dam axis, viewed from the upstream side, are shown in Figs. 4 and 6. The geological investigations have indicated that although the imperviousness of reservoir bed is practically ensured by the nature of the soil, the presence of a porphyrite outcrop necessitated the adoption of special constructional measures to ensure reliable and watertight foundations.

Excavations carried out in 1948 and several testborings, some of which were driven in a horizontal direction, gave very accurate data for this area and provided the basis for developing appropriate methods of conducting the operations.

Dam and outlet structures

When the construction of the Bau Muggeris dam was resumed, in 1947, the work already carried out in the first stage consisted of part of the foundation excavation and about 10,000 cu. m. of stone-and-mortar masonry, in agreement with the original design in which a solid gravity masonry dam was planned. Steel parts for spillway sluices and bottom outlets had also been purchased in conformity with the original design.

An amendment to the original design was then suggested, by which it was proposed to replace the masonry dam with a cellular gravity concrete dam of a type studied by the author and already adopted for other projects and either built or under construction in the Alps and elsewhere. This amendment, which involved considerable economic and technical improvements, was accepted by the company. Some of the existing masonry work had consequently to be removed to accommodate the foundations of the buttresses of the new dam. Within 18 months the construction was completed and the reservoir impounded up to 48 m. of height of the dam, against the 62 m. of the total dam height. The dam adopted in this project is similar, with minor changes, to the well-known hollow-gravity type derived either from the type proposed by Figari since 1900 (a classic example is the Dixence dam in Switzerland) or from the Noetzli type (Don Martin, U.S.A.; Krangede, Sweden; Scais, Italy; Lucendro, Switzerland).

The dam, a straight-axis structure, comprises seven hollow elements, 22 m. wide (Fig. 1), having the geometric outline shown in Figs. 4 and 7, and two solid elements at the abutments. The length of the dam crest is 235 m., and the maximum height 62 m. Access to the cavity of each element is ensured by a 1·60 m. dia. circular opening in one of the side walls, and air circulation within the cavity is provided for by an air vent on the downstream face. A downstream view of the dam is shown in Fig. 1, and a sectional elevation in Fig. 8.

The stability of each single element has been checked as a solid monolith resting on its base, and

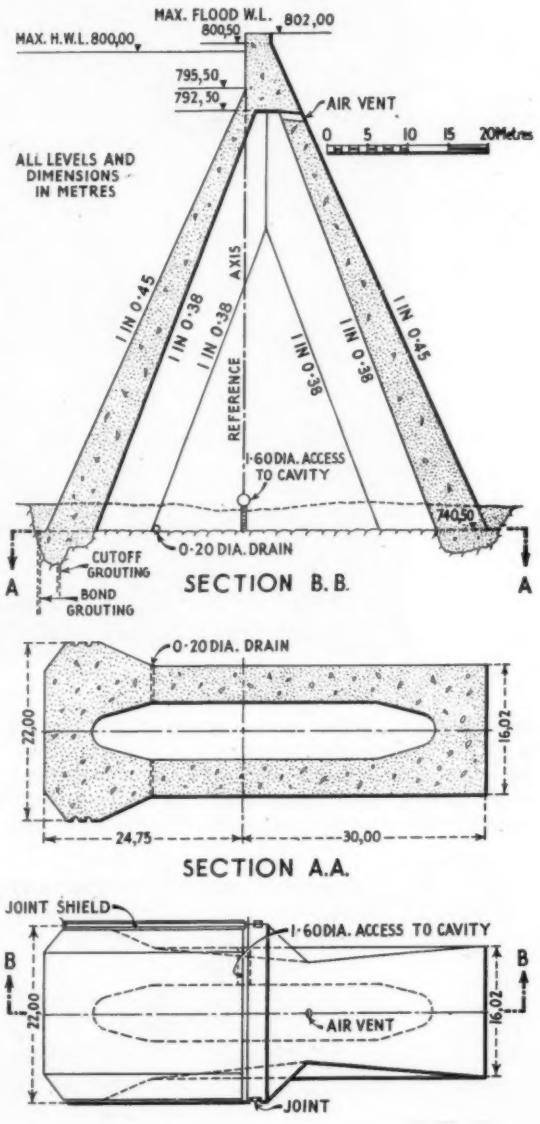


Fig. 7. Typical buttress section of dam

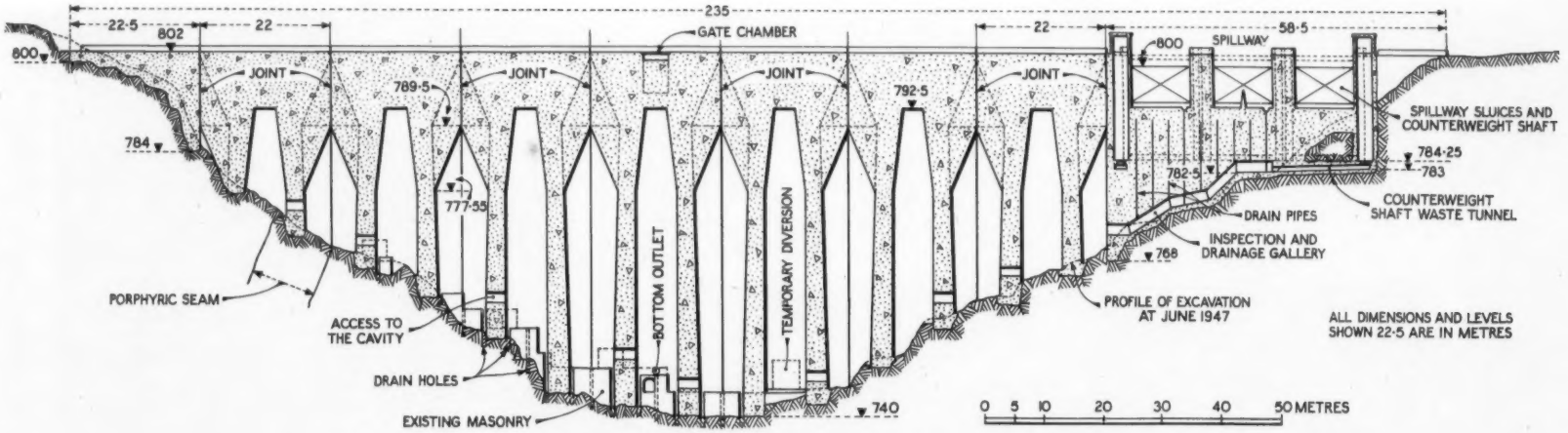


Fig. 8. Cross section along Bau Muggeris dam showing old masonry work and other details

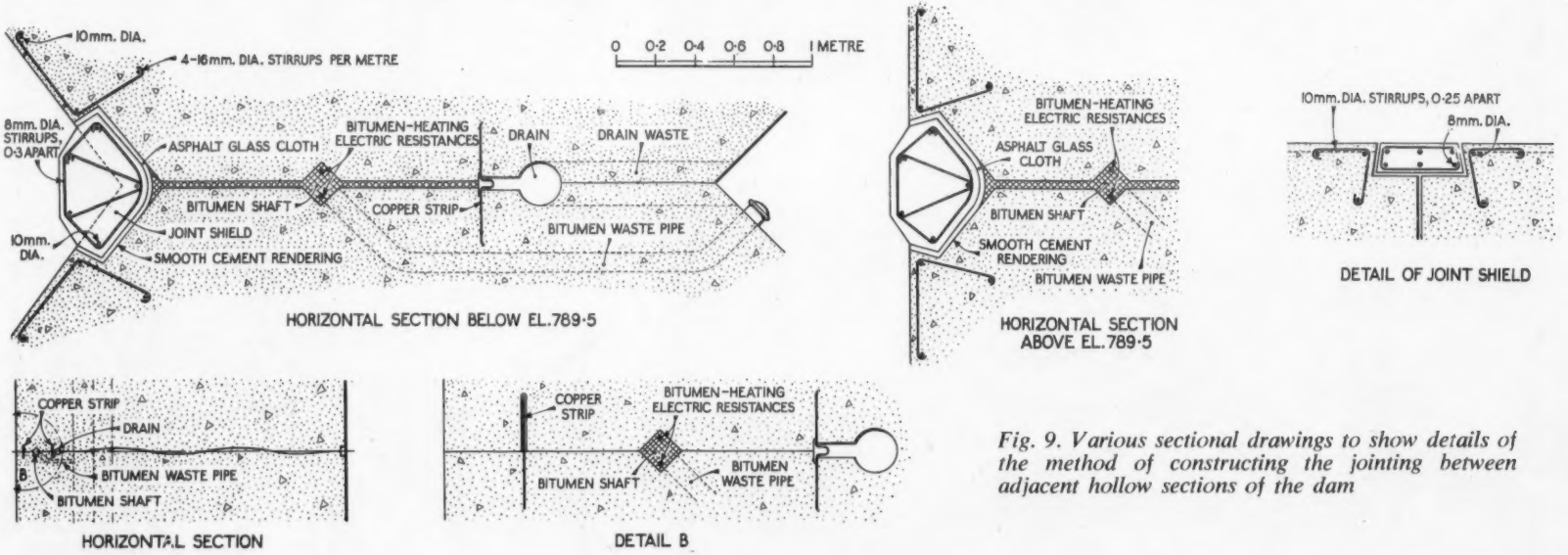


Fig. 9. Various sectional drawings to show details of the method of constructing the jointing between adjacent hollow sections of the dam

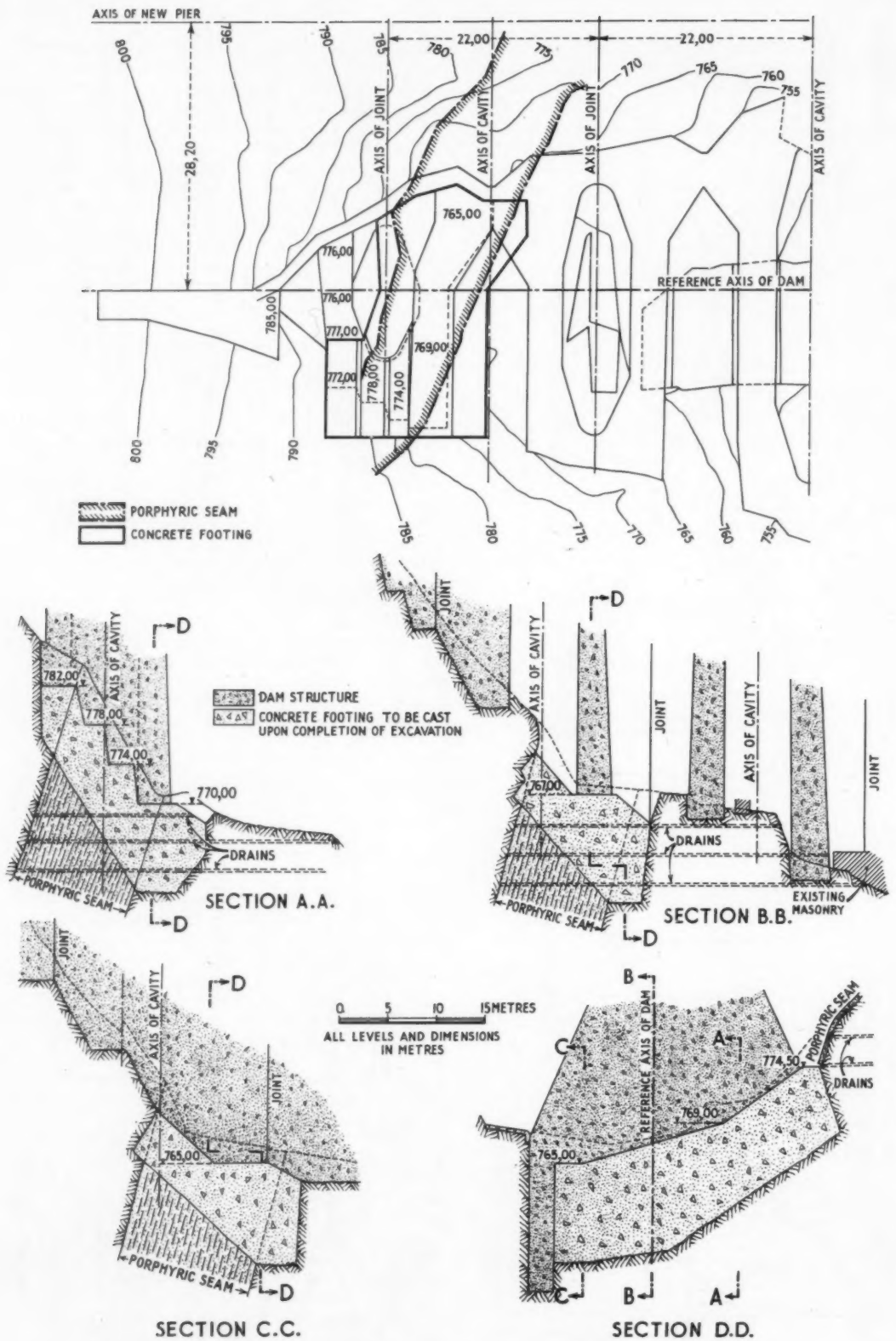


Fig. 10. Plan and vertical sections of concrete footing in region of porphyritic dyke

subject to hydrostatic thrust on the upstream face and uplift pressure on the base joint. Uplift pressure is assumed to be equal to the hydrostatic pressure at the upstream face and to one tenth of the same pressure on the solid part of the buttress along the upstream edge of the cavity: pressure is considered zero along the perimeter of the cavities. Maximum flood water level has been fixed at El.800·50, that is, 0·50 m. higher than effective storage water level (800). The specific weight of concrete is figured in the calculations as 2·3 tons per cu. m.; and that of water is assumed as 1 ton per cu. m.

The maximum compressive stress on horizontal elements shows a peak value of 17·7 kg. per sq. cm. at the joint at El.740·50, for which the maximum principal stress is 21·2 kg. per sq. cm. on the downstream face (compression). Slight tensile stresses of the order of 0·2 kg. per sq. cm. are observed on the upstream face, always considering the principal directions. The ratio between horizontal and vertical loads is 0·656, at elevation 740·50.

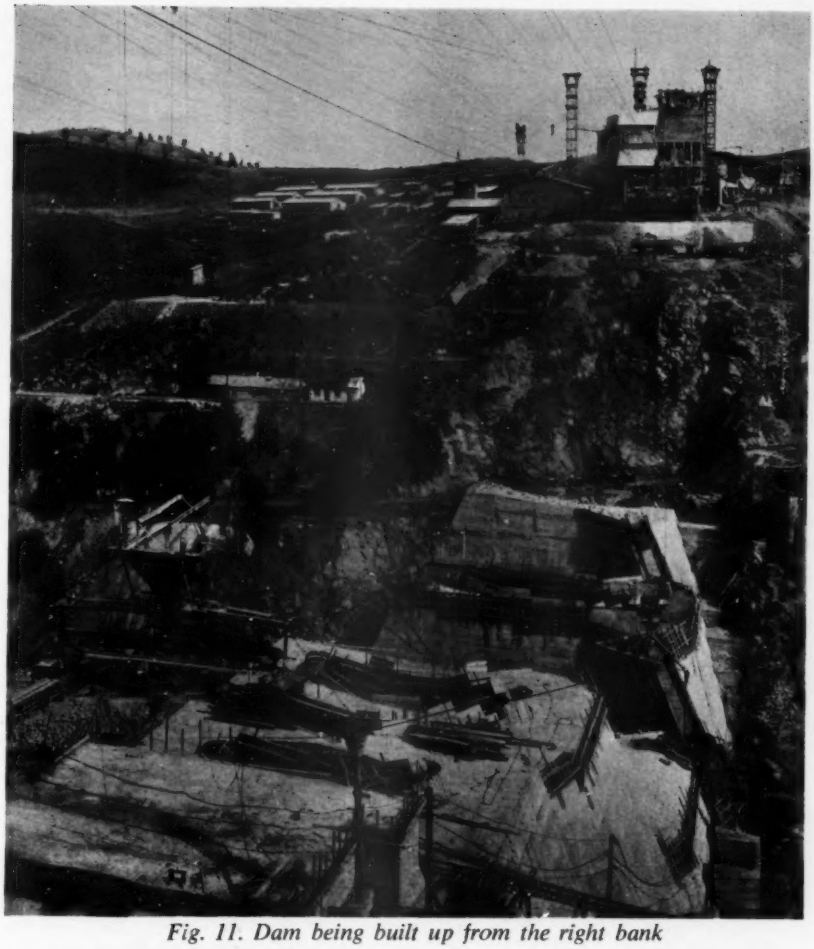


Fig. 11. Dam being built up from the right bank

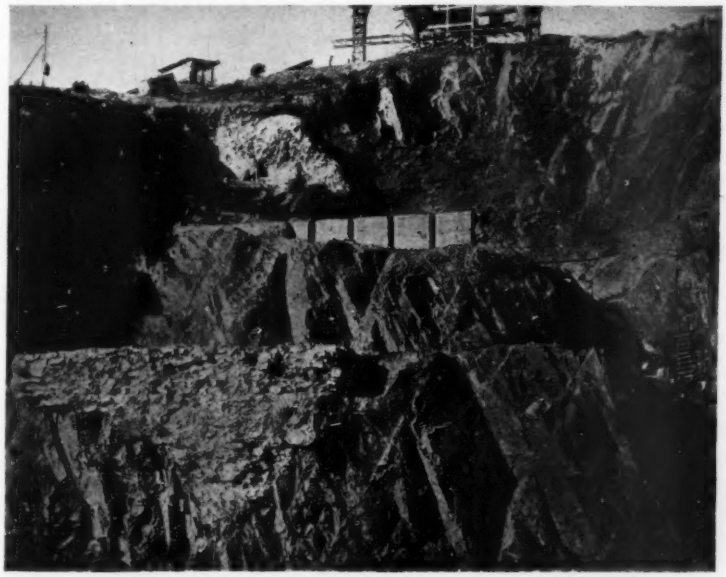


Fig. 12. Dam foundations, right bank, showing remains of earlier stone masonry along downstream edge of porphyritic dyke

Details of the provisions adopted to ensure sealing of the joints between the hollow elements are shown in Fig. 9. Drainage of the foundation rock is ensured for all the elements of the dam, through conveniently sized holes drilled along the perimeter of the cavities.

Special arrangements had to be made in connection with the porphyritic dyke on the right bank, for the foundation of the buttress (element No. 2), which rests partly on this intrusion. A large reinforced foundation slab has been provided in this area to ensure a reliable bond with the foundations on schist and a good hold on the finely fractured material forming the dyke. Im-

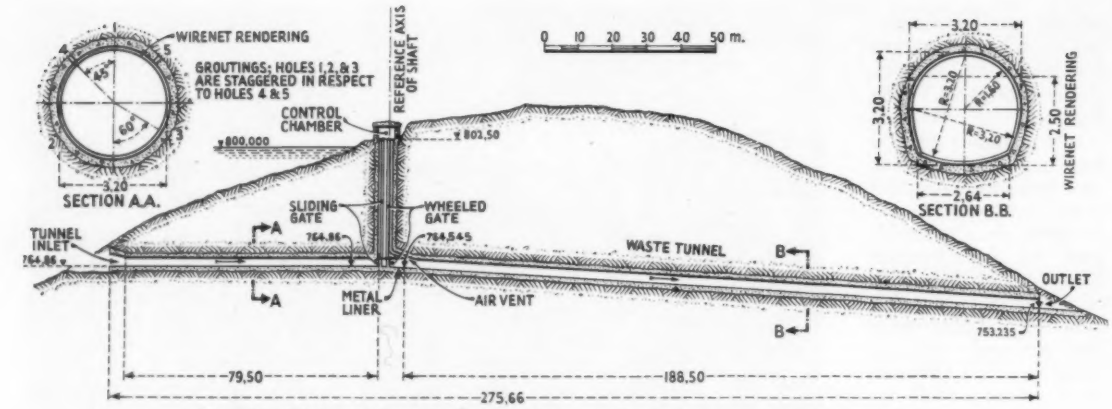


Fig. 13. Main bottom (relief) outlet: profile and characteristic sections

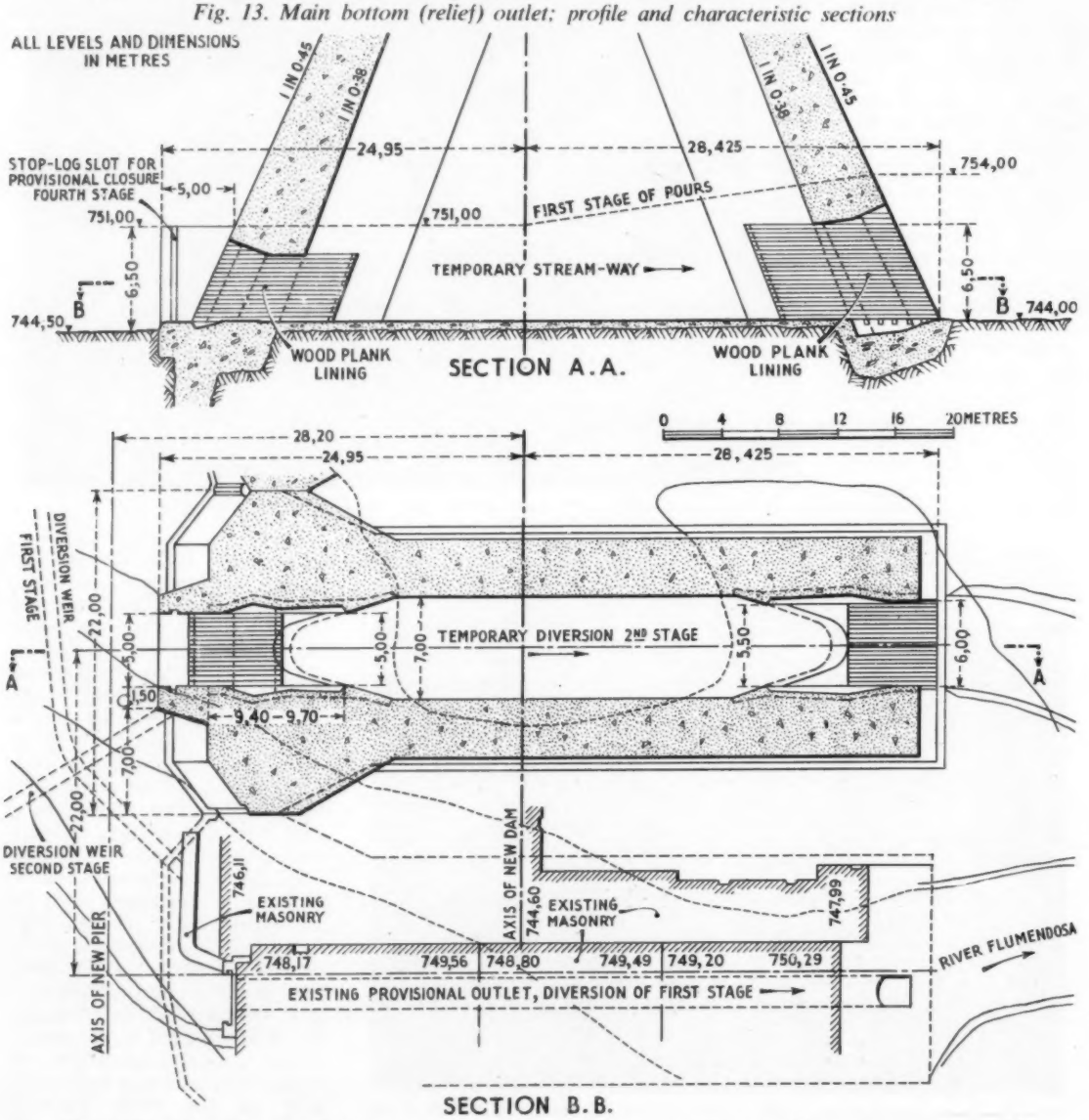


Fig. 14. Sectional method adopted to effect temporary diversion of river through buttress No. 5

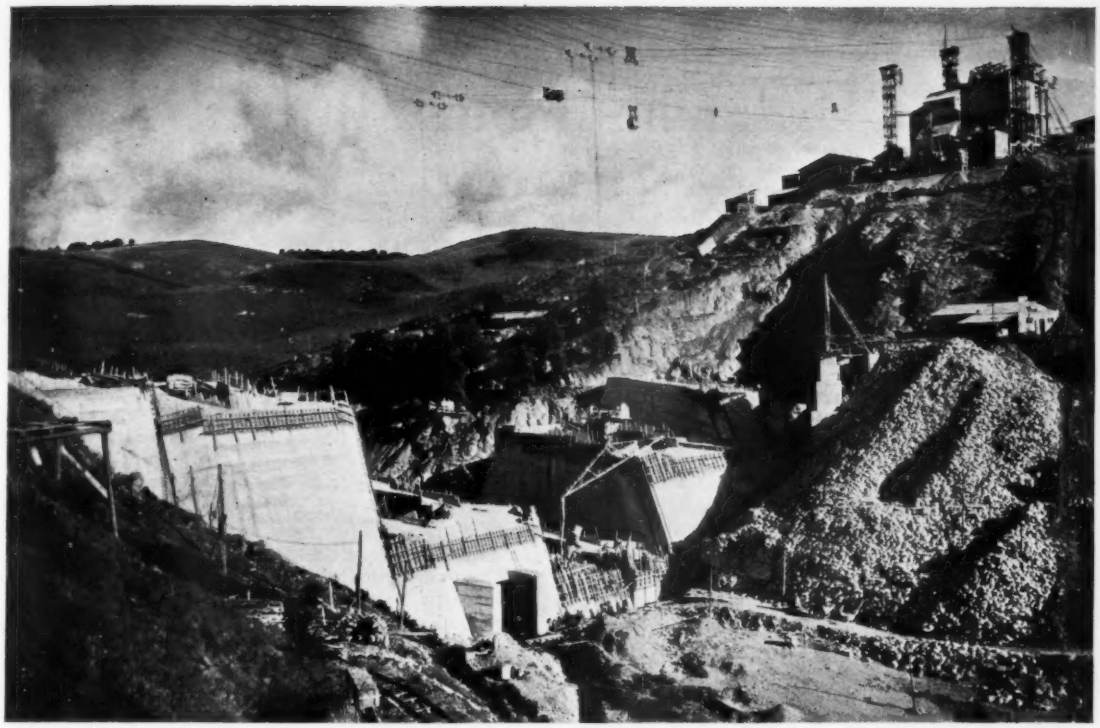


Fig. 15. Dam from upstream showing opening for discharge of water during early stages of construction

provement of the surface was also obtained by pressure-jet washing and subsequent grouting (Fig. 10). A wide system of foundation drainage was provided in this area through shafts and bore-holes driven vertically as well as horizontally.

The solid structure on the left bank, where the spillway is located, has a parabolic profile with a spilling crest at El.794 (this being the sill level of the sluice gate) and reaches a maximum height of 22 m. Drainage in this section is provided through a gallery and a series of vertical shafts. The solid structure on the right abutment has a maximum height of 18 m. and has no peculiar feature. Incidentally, the spilling structures are practically the same as planned in the original stone-masonry design, chiefly because the pertinent steel structures had already been purchased.*

In addition to the spillway, the Bau Muggeris dam has two deep outlets one of which is 32 m. below high-water level and the other 23 m. lower still. The maximum total discharge capacity of the spillway and deep outlets with normal water storage is about 1,050 cu. m. per second, or, with the maximum expected flood-water level, about 1,200 cu. m. per sec. This value, considering the reduction of the flood peak afforded by the spread of the reservoir, corresponds to a peak inflow of about 1,300 cu. m. per sec.

Spillway. The spillway structures consists of three automatic sector gates (each of them 10 m. wide and 6 m. high) installed near the left bank abutment (Fig. 1). Spilled water is collected in an appropriately designed waste channel which, for economical reasons, has been longitudinally divided into two sections with floors at considerably different elevations as will be shown later. The flow that can be discharged through the spillway is 940 cu. m. per sec. with normal water level in the reservoir.

Main bottom outlet. The main bottom outlet consists of a tunnel about 276 m. in length with a 3·20 m. dia. circular cross-section upstream of the gates and horseshoe section downstream of control gates. Two control gates are provided, arranged in series, measuring 2·20 × 2·20 m. and located at the foot of a control shaft (Fig. 13). This outlet can discharge about 110 cu. m. per sec. with water level at El.800.

Subsidiary bottom outlet. This outlet consists of a 1·30 dia. steel pipe crossing buttress No. 4 of the dam. This pipe is controlled at the upstream end by a square 1·50 × 1·50 sliding gate† and at the downstream end by a 0·90 dia. needle valve, placed at El.748·50. Discharge of this outlet is about 18 cu. m. per sec. with normal reservoir storage.

(To be continued)

* The author would have preferred to provide a wide overflow sill in addition to the gate-controlled spillway, but this would have involved changes in design and location.

† Hoisting for this gate has been modified in order to allow the gate to be pulled up to the top of the dam.

Frame-Type Pump. In bulletin No. 52B6691A the Allis-Chalmers Manufacturing Company call attention to a new frame-type centrifugal pump they are marketing, designed to handle most pumping jobs requiring capacities up to 500 g.p.m. and up to heads of 135 ft. Fitted with a V-belt drive, the pump can be mounted in a variety of positions and to any type of prime mover without involving alignment problems, and the head and capacity requirements can be adjusted by altering the sheave side of the drive.

Governing by Hydraulic Impulse Brake

We give an abridged account of a paper presented by Paul N. Wilson, M.A., A.M.I.C.E., M.I.Mech.E., to the British Hydromechanics Research Association.

MUCH has been written about the governing of water turbines, and many types of governor have been produced. The main problem which confronts the designer is the acceleration and retardation of large masses of water in the pressure penstock when load is accepted or rejected by the turbine.

The rate of flow of water to the wheel of a reaction turbine is controlled by varying the opening of the guide-vanes or gates which surround it. Unless ancillary equipment is provided, this involves the acceleration or retardation of the total mass of water in the pressure penstock. In order to prevent excessive rise in speed when load is rejected, or excessive fall in speed when it is accepted, the operating time of the governor must be rapid, usually a matter of from 2 to 5 seconds, and this is bound to create pressure waves which may, if they are severe, produce surging and instability of governing.

The worst condition is deemed to occur when full load is suddenly rejected, but serious pressure rises can also take place when the guide-vanes are opened to accept load. The condition when from 25 to 50 per cent. of full load is suddenly thrown on can, in some cases, be the most difficult which a governor has to handle.

If the ratio of the length of the pressure penstock to the working head on the turbine is not greater than 3 or 4 to 1, the closing time of the governor and the flywheel effect of the rotating element can usually be so adjusted that satisfactory governing is obtained though the speed and pressure rise with heavy load rejection may be considerable. Should the ratio exceed this figure, special precautions must usually be taken to assist good governing.

The first method consists in building a surge tower sufficiently close to the turbine to ensure that the effective length of the pressure penstock comes within the required limits. Surge towers are expensive and often the profile of the penstock is such that it is difficult to incorporate one.

The second method is to provide a governor-operated relief or by-pass valve. When a heavy load is rejected the relief valve opens and, in theory, it by-passes the volume of water which has been shut off from the turbine wheel. It then closes slowly under the action of a dashpot, the water being discharged to the turbine tailrace. With full load rejection the by-pass valve must open sufficiently to discharge the full volume of water which was flowing through the turbine. For a large turbine the size and cost of the relief valve is considerable, and special precautions must be taken to ensure that the energy contained in

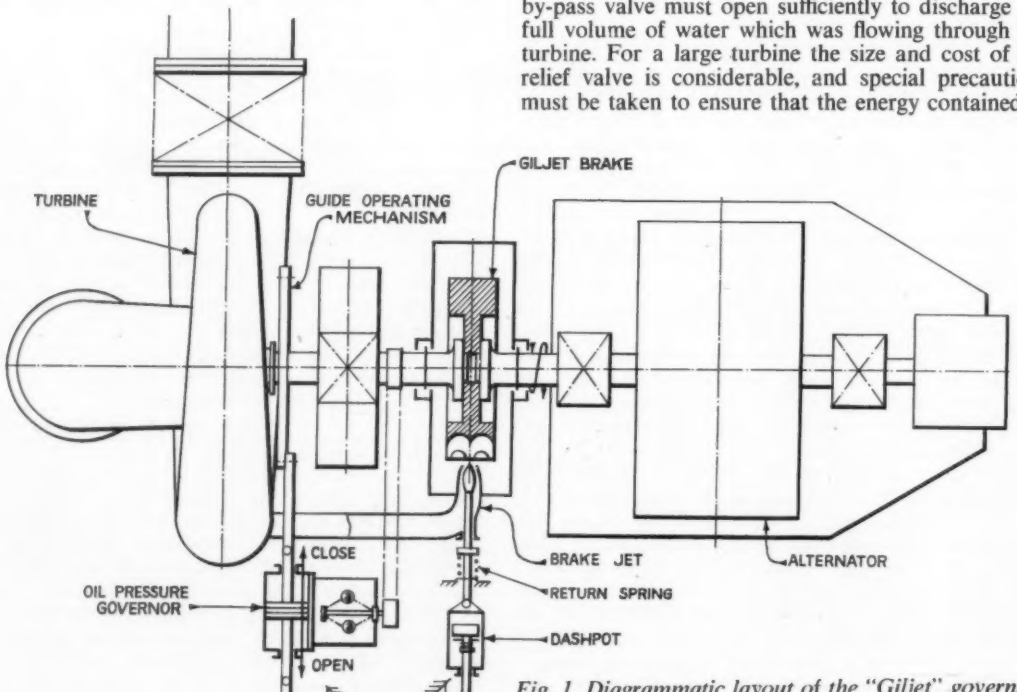


Fig. 1. Diagrammatic layout of the "Giljet" governing system

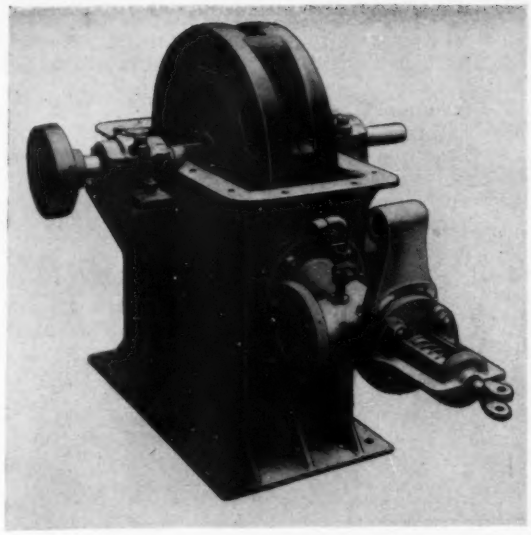


Fig. 2. First experimental flywheel brake

the discharge water is dissipated safely without causing shock or vibration.

Wear on the seating of a relief valve allows continuous waste of water and reseating is a major repair which may involve the shutting down of the turbine for some days.

Governing by Artificial Load

A less conventional method of governing is by imposing an artificial load on the turbine, so that as the useful load is varied up or down, the artificial load is complementary, the total load on the turbine thus remaining constant. The author's firm* has for many years manufactured an eddy current electric absorption brake governor, which dissipates surplus electrical energy in heat, and so maintains a constant load on the turbine. These electric brake governors have a particular application to waterworks, where it often happens that the turbine is required to pass a constant volume of water regardless of wide variations in the electrical load. The turbine guide vanes are set to pass the correct quantity of water, and variations in the outgoing load are automatically compensated for by the electric brake governor.

The satisfactory results obtained by this method of governing with an artificial load have naturally tended to make the author and his colleagues consider other methods of imposing such a load, and it is for this reason that the use of the hydraulic impulse brake first suggested itself.

The Hydraulic Impulse Brake

During the war the author's firm carried out certain experimental work concerned with a reversible Pelton wheel driving a flywheel. In studying the results of this work he was impressed by the speed with which the Pelton wheel, and its associated flywheel, could be brought to rest when a reversing jet was turned on. If, by allowing some form of Pelton wheel to rotate *towards* a jet of water, a powerful retarding torque could be exerted when using a relatively small volume of water, it became clear that an entirely new field for imposing an artificial load on a turbine might be explored.

The preliminary sketch which the author made for the governing system is almost identical with the arrangement finally adopted, which is shown diagrammatically in Fig. 1, and to which the trade name "Giljet" governing system has been given.

Referring to this diagram, it will be seen that the flywheel is of special construction, having formed in its rim a series of Pelton wheel type buckets which rotate *towards* a jet fitted with a spear nozzle. The design of flywheel-brake employed can be seen in Figs. 2 and 4. A standard oil pressure governor controls the turbine guide-vanes, but coupled to its main rocking shaft is a set of levers connected through a dashpot mechanism to the spear valve. The dashpot piston is free to move rapidly when the turbine speed falls, and the governor operates to open the guide-vanes, but its movement is restricted by means of an orifice when the turbine guide-vanes close due to rejection of load and a rise in speed.

Assume that a turbine is driving an electric generator operating steadily at full load, and the breaker suddenly trips, throwing the load off: the turbine speed will rise, causing a closing movement of the guide-vane-operating mechanism, and an opening movement of the "Giljet" spear. When the guide-vanes have closed through about 10 per cent. of their travel, the spear nozzle will open fully, and the retarding torque exerted on the flywheel-brake will be such that approximately nine-tenths of the power of the turbine is immediately absorbed. There will be a slight rise

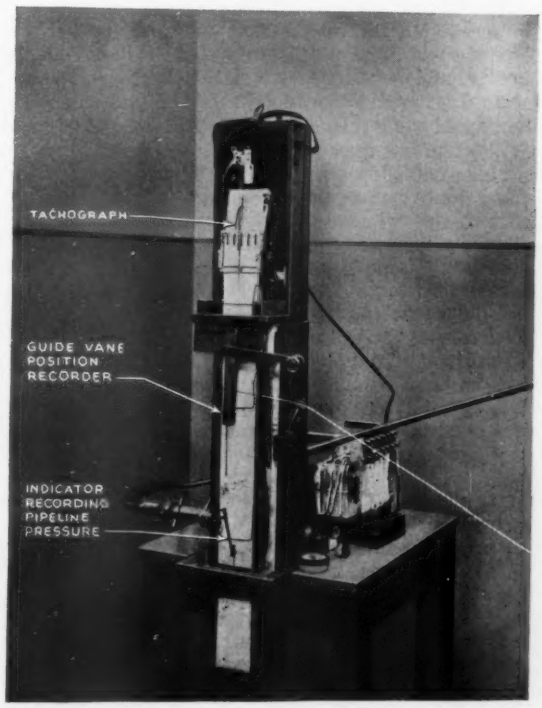


Fig. 3. Tachograph, pressure and guide-vane-opening recorder at Islay Estates

*Gilbert Gilkes & Gordon Limited

Fig. 4. Cast-steel flywheel brake for Kerry Falls power station, Gairloch, designed to absorb 725 b.h.p. at 1,000 r.p.m. when supplied with water under a head of 160 ft.

in speed, but the rate of flow of water through the pipeline will remain almost unchanged. If the linkage between the rocking shaft of the governor and the spear were solid, the turbine would continue to operate indefinitely at this setting of the guide-vanes and "Giljet" unless there were an increase in the load on the alternator, in which case the fall in speed would cause a movement of the governor rocking shaft which would slightly close the spear, and re-proportion the load between the alternator and the hydraulic brake.

Due to the incorporation of a dashpot in the mechanism, the spear will gradually close the nozzle, thus reducing the braking jet, and the retarding torque on the flywheel-brake. The gradual reduction in load allows the governor to close the turbine guide-vanes. The rate of closing is controlled by the setting of the dashpot orifice.

Having decided upon the principle of operation it was then necessary to estimate the proportion of water passed by the turbine which would be necessary to absorb the full load. The calculation is a straightforward one involving the change in momentum of the water issuing from the jet.

The following symbols have been adopted:—

v = jet volocity in ft. per sec. = $0{\cdot}98\sqrt{2gH}$.
V = pitch line velocity of flywheel-brake in ft. per second.
N = revolutions per second.
M = lb. of water per second passing through jet.
H = head in feet at jet.
P = power in b.h.p. absorbed by brake.
$\emptyset$ = angle of discharge from buckets.
η = "roughness factor" of buckets.

Relative velocity of water entering bucket $= v+V$ (1)

Relative velocity of water leaving bucket in direction of motion $= (v+V)\ \eta\ Cos\ \emptyset$ ($\emptyset$ = angle of discharge) . . . . . (2)

Force exerted on bucket =

$$\frac{M}{g}\left((v+V)+(v+V)\eta\,Cos\,\emptyset\right) \quad . \quad . \quad . \quad . \quad (3)$$

Power absorbed,

$$P=\frac{MV}{550\,g}\left((v+V)+(v+V)\eta\,Cos\,\emptyset\right) \quad . \quad . \quad (4)$$

The pitch line velocity must be kept as high as possible. It is normally fixed by the permissible rim speed which, for a cast steel brake, has been set at 12,000 ft. per min. at rated speed. Knowing the power to be absorbed, "M" can be calculated. It varies from about 3 per cent. of the full load rate of flow of the turbine for low heads to 10 per cent. or more on high heads.

In the case of the Gairloch installation, which will be discussed later, the conditions were as follows:—

v = 101 ft. per sec.
V = 138·2 ft. per sec.
N = 16·6 revs. per sec. (1,000 r.p.m.).
M = 242 lb. per sec. (3·87 cusecs).
H = 165 feet.
P = 706 b.h.p. (found by observation).
$\emptyset$ = 30°.
η = 0·65.

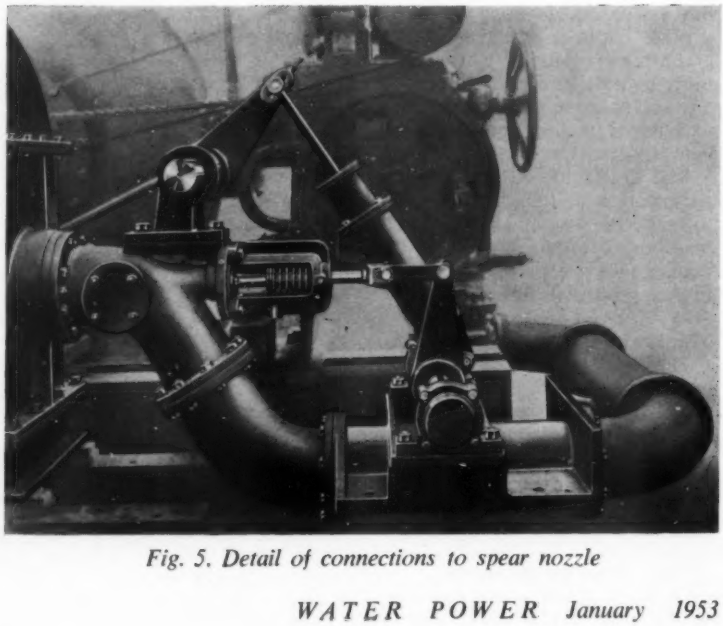


Fig. 5. Detail of connections to spear nozzle

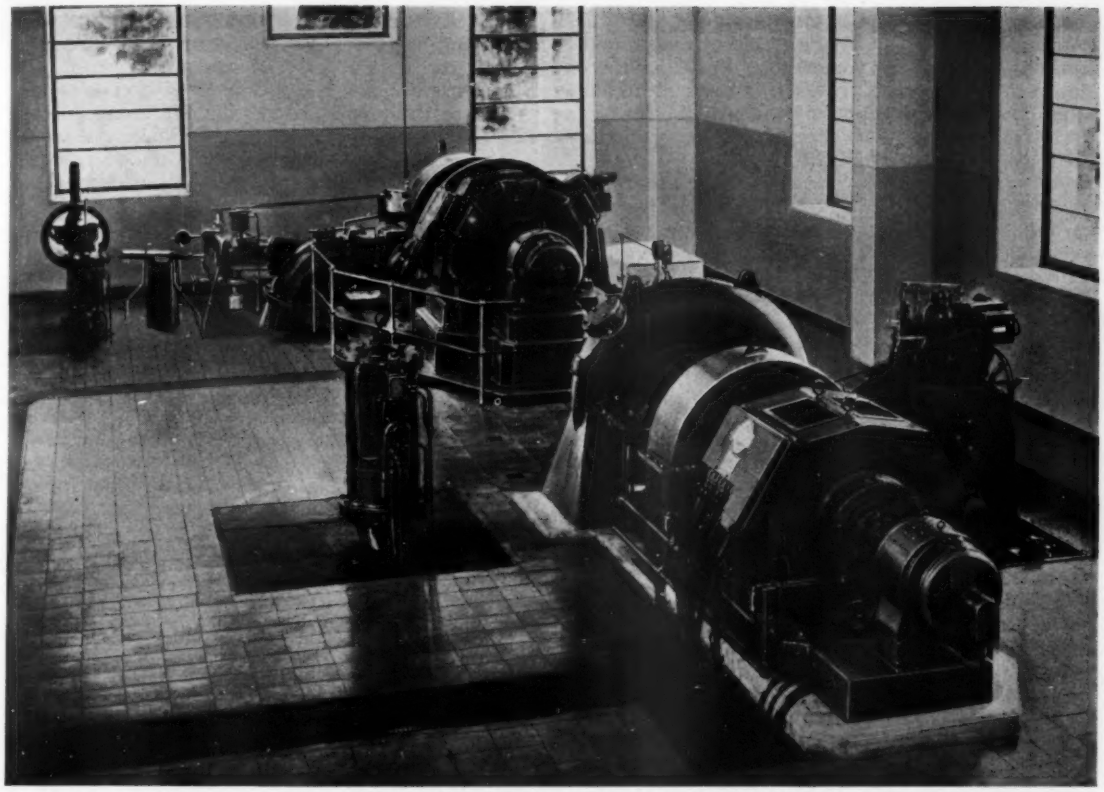


Fig. 6. Kerry Falls power station, showing 500 kW Francis turbine with "Giljet" governing in the foreground and 250 kW Turgo impulse wheel in the background

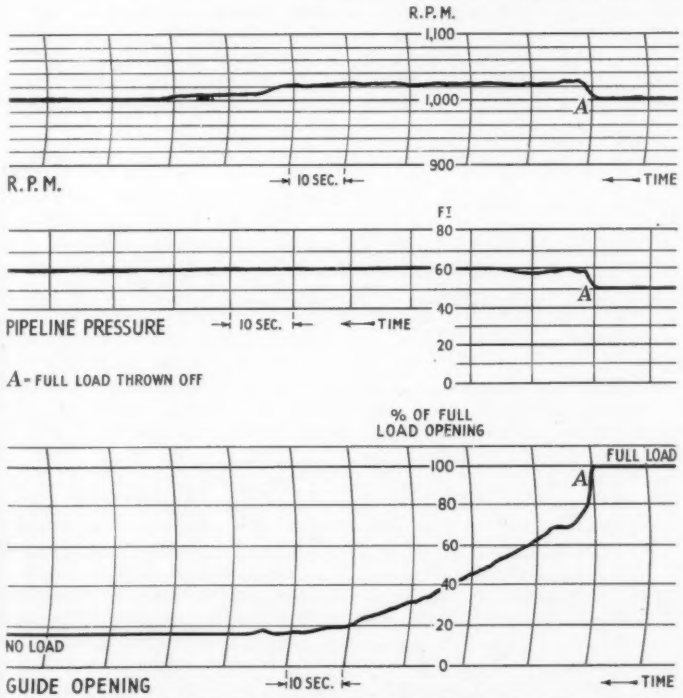


Fig. 7. Speed, guide-vane-opening, and penstock pressure readings obtained with full-load rejection at Islay Estates

The dimensions of the brake, nozzle, etc., were calculated from theory and were checked by the experimental result obtained with a smaller unit using a cast iron flywheel-brake. The roughness factor at Gairloch—which had a cast steel brake—was found to be a little higher than anticipated. It had been intended that the brake should absorb 725 b.h.p. at 1,000 r.p.m. whereas, in fact, it absorbed 706 b.h.p. With a slight speed rise an output of 731 b.h.p. was absorbed. The turbine passed some 42 cusecs and the quantity of water required by the brake was 9·25 per cent. of this quantity.

Test Bed Experiments

An experimental flywheel-brake was built, designed to absorb 35 b.h.p. at a speed of 1,430 r.p.m. when supplied with water at a pressure of 55 ft. head. This brake, with the top cover of the casing removed, is shown in Fig. 2. The first tests were made to ensure that when operating light the amount of power absorbed by the brake was reasonably small. After some modification had been

made to the casing it was found that the power absorbed was 0·47 b.h.p. This includes bearing friction, and was little, if any, greater than would have been absorbed by a normal flywheel of the same dimensions. The correct design of the flywheel-brake to ensure maximum power absorption and minimum air resistance is an important feature.

A water turbine complete with brake and electric generator was then set up on the test bed, the water turbine being supplied by means of a motor-driven centrifugal pump. Tests showed that very slow closing of the turbine guide-vanes could be obtained, whilst with full load rejection the speed rise could be restricted to 4 or 5 per cent.

First Working Installation

Shortly afterwards a 20 kW hydro-electric set was supplied to the Islay Estates Ltd., Islay, Scotland. This turbine operates under a net working head of 60 ft., but is fed through a very old pressure penstock 1,800 ft. long. It is required to supply directly the electrical load of the estate, and had the "Giljet" governing system not been installed it would have been necessary to provide a governor-operated relief valve.

Fig. 3 shows the apparatus for obtaining the combined speed, pressure in penstock and guide-vane opening records with load changes. The speed is recorded from an electrical tachometer, the pressure from a steam-engine type indicator, and the guide-vane opening by a wire connection to the guide-vane mechanism. Fig. 7 gives a typical result. It will be seen that with full load rejection the speed rise was only about 3 per cent. above the final settled speed, and the pressure in the penstock never rose higher than static head. The guide-vane opening curve indicates the immediate quick closure as the load is thrown off, and the "Giljet" spear opens. Thereafter the guide-vanes close slowly and steadily, and it will be seen that the total closing time was approximately one minute. This unit has now been in commercial operation for three years.

Kerry Falls Scheme, Ross-shire

Before the experiments had been carried out on the Islay Estates turbine, the author's firm had obtained the order for the second hydro-electric set for installation at the Kerry Falls Power Station of the North of Scotland Hydro-Electric Board. This power station is supplied by a pressure penstock 4,300 ft. long, the static head being 188·5 ft. The first unit was rated at 250 kW, and it was possible to put in a high specific speed "Turgo" impulse wheel driving an alternator at a speed of 333 r.p.m. This turbine is fitted with deflector governing and slow closing spear control, and satisfactory governing was obtained in spite of the great length of pipeline relative to the head.

The second unit was to be rated at 500 kW and it was clear that for this output it would be essential to install a Francis turbine as the speed would be much too low with an impulse wheel. The consulting engineers, Messrs. Strain and Robertson, of Glasgow, and the North of Scotland Hydro-Electric Board agreed that the "Giljet" governing system should be employed, and the manufacturers guaranteed that with full load rejection the speed rise would not exceed 12 per cent. above final settled speed or the pressure rise in the penstock 15 per cent. above static head. No guarantee of performance with loads thrown on were given.

Fig. 4 shows the cast steel flywheel-brake which was designed to absorb 725 b.h.p. at 1,000 r.p.m. when supplied with water under a pressure of approximately 160 ft. of water.

Fig. 5 is a detail of the pipes supplying the "Giljet" nozzle from the turbine casing, and shows the operating links and levers. This is the position which the mechanism will take up about 0·5 seconds after full load has been rejected. The turbine guides have closed slightly, while the spear has opened to its full extent, thus admitting the maximum braking jet to the flywheel disc and restraining any further speed rise on the turbine.

Fig. 6 is a view inside the power station showing the Francis turbine with "Giljet" governing system in the foreground.

Temporary testing equipment was provided by the alternator manufacturers, Bruce Peebles & Co. Ltd. This consisted of three sets of tapped resistances placed in tubs of water outside the power station and connected to the alternator terminals through an oil circuit breaker. Different loads could be obtained by altering the tappings and by the control of voltage. No special arrangements were made to enable the load to be put on gradually, and the sudden throwing on of heavy loads produced some interesting results.

The pressure penstock is long in relation to the head and due to constructional difficulties it was found impossible to lay it on a downward grade throughout its full length. There is a high point about 1,300 ft. from the intake where the crown of the pipe

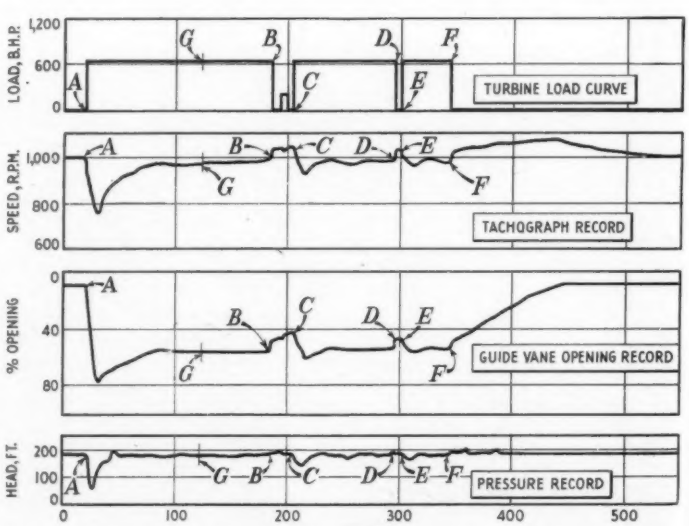


Fig. 8. Speed, guide-vane-opening, and pressure records taken at Kerry Falls under a load rejection of 622 b.h.p.

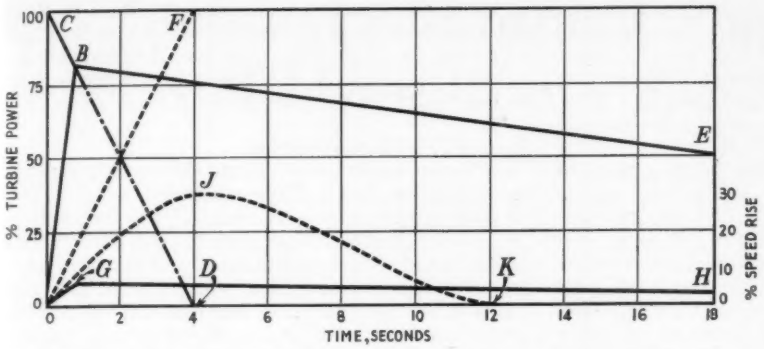


Fig. 9. Calculated speed-rise curves of full-load rejection with "Giljet" governing and conventional relief-valve operation

is 18 ft. below the crest of the intake dam. An air valve is fitted at this point.

As will be seen from the record charts, the operation with load rejection was satisfactory and from a hydraulic point of view the load acceptance conditions were perhaps more interesting.

It was found that when half load was suddenly thrown on, the pressure dropped to about 100 ft. in the turbine casing, and the subsequent surge rose to between 200 and 230 ft. With full load thrown on, the pressure drop was even greater, falling to some 50 ft., but the following surge was less severe. Observations at the air valve proved that when a heavy load was thrown on, a large blast of air was drawn in, some of which was expelled a few seconds later as the return pressure wave came up the line. There is, however, little doubt that considerable quantities of air were entrained with the water and sudden but otherwise unaccountable movements of the governor which would take place anywhere from 20 to 40 minutes after a heavy load had been thrown on could only be accounted for by assuming that the entrained air was at that moment passing through the turbine. Complete stability would be regained after a few seconds.

The consulting engineers stipulated that the operation of the governor should be stable when full load was suddenly thrown off, and the breaker remade three seconds later. Acceptance was therefore based upon the tests being carried out generally along the lines of those indicated in the chart shown in Fig. 8. A detailed study of these charts will be of interest. The vertical lines indicate time intervals of 10 seconds and the chart is read from left to right.

From the beginning of the chart to point *A* the turbine is operating steadily at no load at a speed of 1,000 r.p.m. At point *A* load is suddenly thrown on, and the speed drops to 770 r.p.m. The turbine guide-vanes open to 80 per cent. and the pressure in the pressure penstock drops from 180 to 50 ft. Within a few seconds there is a rapid build-up in pressure, and the turbine guides close to 55 per cent. At the same time the speed rises steadily to 955 r.p.m. It is interesting to note the pressure surge to 200 ft. head which takes place as the pressure wave comes back down the pipeline.

At point *G* the chart was stopped until settled conditions were obtained, and was then restarted. At point *B* load was rejected, it being the intention to throw it on again after three seconds. Unfortunately, the breaker did not go in correctly, and the load was not again thrown on until point *C* is reached. It will be seen that with load rejection there was an immediate speed rise to 1,035 r.p.m. The pressure variations between point *B* and *C* were slight.

When the load was thrown on there was again a sudden drop in pressure to just under 150 ft. The speed fell to 935 r.p.m. and the guide-vanes opened to 60 per cent. Thereafter conditions settled until point *D* was reached. The correct procedure for throwing load off and on again in three seconds was carried out at *D* and *E*. During earlier tests experiments were carried out by throwing full load on and off at regular intervals several times, and it was impossible to set up any hunting in the governor or surging in the penstock.

At point *F* the load was finally thrown off. The speed rose rapidly to 1,025 r.p.m. and subsequently very slowly to 1,070 r.p.m. There was a quick closing movement of the guide-vanes, followed by a long and steady closure. There was some variation in pressure as the pressure waves travelled up and down the penstock, but the maximum rise did not exceed 6 per cent. above the static head.

The closing time of the "Giljet" dashpot was approximately 50 seconds. Other tests had shown that a lower speed rise could be obtained by increasing the closing time, but a rise of 6 per cent. above final settled speed was considered satisfactory. The relatively slow speed rise up to maximum gave ample time for the automatic voltage regulator to work, and the greatest voltage rise with full load rejection was only in the order of 13 per cent.

It will, of course, be appreciated that with small load changes the governor operates in the normal way without opening the spear.

The noise made by the brake when absorbing the full output of the turbine is difficult to estimate, but is comparable to the noise which is made when the full power of an equivalent impulse turbine is being absorbed by deflection of the jet. There was no appreciable vibration, and it was possible to balance a half-crown on the turbine and alternator bearings on either side of the flywheel when full load was being absorbed. The set was run for some hours with the brake absorbing the maximum turbine output, and the only effect was a slight increase in the temperature of the coupling end bearing of the alternator.

Comparison with Relief Valve Operation

It is interesting to compare the governing obtained with the "Giljet" system with the corresponding performance had a governor-operated relief valve been fitted. Fig. 9 is plotted on a time base, with percentage of turbine power and percentage speed rise as ordinates. Full lines are for the "Giljet" and dotted lines for the conventional governor with relief valve.

Consider first the "Giljet" system. At zero, full load

is instantaneously rejected. The turbine guide-vanes, set for a 4-sec. closing time, begin to close, and the "Giljet" spear, set to open in 0·5 sec., starts to open. The power developed by the turbine follows the line *C*, *B* and *D*, and the power absorbed by the brake follows the line *O B*. Where the two intersect stability will be achieved. The area *O C B* represents the energy which must be stored in the rotating parts. In this case the full power is taken as 706 b.h.p. giving a value of stored energy of 87,000 ft.lb. The flywheel effect, WR^2, of the rotating mass is 6,550 lb.ft.^{2}, and the theoretical speed rise will be from 1,000 to 1,037 r.p.m. This approximates closely to the actual speed rise obtained. Thereafter, assuming that the reduction of power on the brake and the reduction of power input to the turbine by closing the guide-vanes follows the same line, the speed will remain constant until the brake is closed, when it will return to normal.*

With a conventional governor, set to close in four seconds and opening the relief valve in the same time, and assuming that there is no pressure rise, the power input to the turbine will follow the line *C D*, and the energy to be stored will be represented by the area *O C D*, equal to 770,000 ft. lb. The theoretical speed rise will be to 1,310 r.p.m. in four seconds, and the rate of return to normal will depend upon the characteristics of the turbine and governor.

If the governor closing time were reduced to 3 sec. it would be necessary to increase the total flywheel effect from 6,550 lb.ft.^{2} to 11,350 lb.ft.^{2} to limit the speed rise to 15 per cent. This would necessitate increasing the weight of the flywheel from the present figure of 3,280 lb. to 6,000 lb.

* This condition obtained at Islay Estates, see Fig. 7 top curve. At Kerry Falls the rate of reduction in braking power was slightly more rapid than the reduction of power input to the turbine, thus allowing a further slight speed rise.

More Powerful Applications

A further 1,650 kW unit is under construction for the Skeidsfoss Hydro-Electric Scheme, Iceland. This turbine, operating on a net head of 130 feet, will be fed by a reinforced concrete penstock 2,100 feet long which already supplies a turbine of American manufacture of the same size, fitted with governor and relief valve. It is anticipated that this unit will be installed and tested during the course of the next 12 months when it will be possible to carry out a direct comparison between operation with two different types of speed control.

Acknowledgments

The author is particularly grateful to the North of Scotland Hydro-Electric Board and their mechanical and electrical consultants, Messrs. Strain and Robertson, of Glasgow, for the assistance given in the carrying out of tests, and for permission to reproduce the majority of the curves and illustrations in this paper.

He would also like to thank Messrs. Bruce Peebles & Co. Ltd. for their willing co-operation during testing, and Messrs. Gilbert Gilkes & Gordon Ltd., who manufactured all the turbine and governing equipment.

B.S. Terms Relating to Welding and Cutting

The British Standards Institution has recently published a revised version of their Glossary of Terms Relating to the Welding and Cutting of Metals. The increase in the application of welding which resulted from the war and the many new techniques developed since the 1939 edition (B.S. 499) have necessitated a much more comprehensive treatment of the subject than was given previously. In view of the magnitude of the subject it was decided to divide the Glossary into a number of sections dealing respectively with: (a) Terms common to most types of welding; (b) Welding with pressure; (c) Fusion welding (welding without pressure); (d) Brazing and bronze welding; (e) Testing; (f) Weld imperfections; (g) Scheme of symbols; (h) Cutting.

The reasons for most of the divisions are obvious but it may be mentioned that some were adopted in order to keep together terms used in special fields. This procedure enables related terms to be associated and should simplify reference. The largest sections are naturally those relating to welding with pressure and to fusion welding. These, like the other sections, deal fully with the terminology applicable to the techniques and equipment. The separate section on testing contains many terms which have an application to diverse welding practices and by giving greater prominence to preferred terms it encourages general use.

The scheme of symbols in Section 7 (which has already been published separately) represents a considerable advance on that given in the appendix to the 1939 edition. As previously announced, this scheme differs radically from former procedure in order to comply with the general move towards achieving greater co-ordination between American, Canadian and British practice which originated at the Ottawa Conference in 1945.

The standard also includes the publication known previously as B.S. 449 : Part 2, which deals with those terms relating to imperfections in welds which are appropriate for radiographic examination.

The entire publication is illustrated with sketches and line drawings: the section on radiographic examination includes reproductions of radiographs and the scheme of symbols is profusely illustrated with examples showing its application. An interesting item is a chart showing the derivation of the various welding and cutting processes. The publication is completed by means of a fully cross-referenced index of all terms dealt with.

Copies of this standard (B.S. 499/1952) may be obtained from the British Standards Institution, Sales Branch, 24 Victoria Street, London, S.W.1. Price 21s.

The Pykara and Moyar Power Development. In connection with the article we published under this title in our November and December 1952 issues, we are informed that the third and fourth pipelines were also supplied and erected by the Ferrum organisation —Ferrum (England) Limited, London, and Ferrum Montage A.S., Oslo. The No. 3 line was, of course, installed before the war and is 3,120 m. long, 1,066/952mm. diameter, and has a total weight of 2,950 tons. The No. 4 line was ordered in 1947 and erection was completed early in 1952; it is 2,725 m. long, 1,066/990 mm. diameter, and weighs 3,000 tons. In both lines the head is 936 m. (3,070 ft.), the thickness of the plate ranging from 12 mm. at the top to 47 mm. at the bottom.

Civil and Mechanical Engineering Aspects of Hydro-Power Development—IV

The last of four post-graduate lectures given by P. W. Seewer, Consulting Engineer to the English Electric Co. Ltd., to the Hydro-Power Course at the Imperial College of Science and Technology, City and Guilds College, South Kensington, London.

THE governing of hydro-electric plant, whether destined for public service, traction or industry, is dictated by the necessity to ensure safe and continuous operation resulting in minimum of interruption in service. It must also keep the speed variations and, therefore, the frequency, consequent on load or head changes within very small limits. One important task is to obviate detrimental or dangerous pressure fluctuations in the hydraulic system and to provide all necessary safety devices.

The close speed variations depend largely on the sensitiveness of the governor, the inertia of the flowing water, the flywheel effect which can be incorporated in the rotating elements, and the permissible waterhammer in the conduits. The solution of the regulating problem therefore differs from one plant to another and calls for safe control of the necessary regulating efforts, which are often considerable, by the governor servomotors.

Easy synchronising and paralelling of plant must be brought about, and in many cases synchronised bypasses must be provided to ensure the harmless destruction of the kinetic energy of the flowing water in case of load drop. In case of load increase, the regularity is bound up with the necessary time limit during which the water masses can be accelerated without creating a detrimental negative pressure drop; this largely depends on the physical conditions of the conduits.

In the first place, satisfactory regulation calls for the provision of a centrifugal device, operated from the main shaft either by belt or the more modern semi-flexible mechanical or synchro-electrical devices, which controls the governor servomotors proper by the intermediary of one or several compensated relays. The sensitiveness of the centrifugal device must be such as to respond to speed variations not exceeding 0·08 per cent. The neutralising (i.e. compensation of the operating movement) is brought about by mechanical or hydraulic flexible return-motion devices, preferably of an asymptotic characteristic, to ensure the necessary proper and rapid damping of the fluctuations in pressure and speed.

On most governors the permanent speed variation is adjustable up to, say, 4 per cent. but can be adjusted in operation down to 0 per cent. (isodrome regulation) so that the responsiveness of the set running in parallel can be adjusted at will. Speed adjustment, for plus or minus 5 per cent. or more, for synchronising or load variation, is brought about by hand or electric remote control influencing either the statism of the centrifugal device or its neutral position.

For the momentary speed variation in case of full,

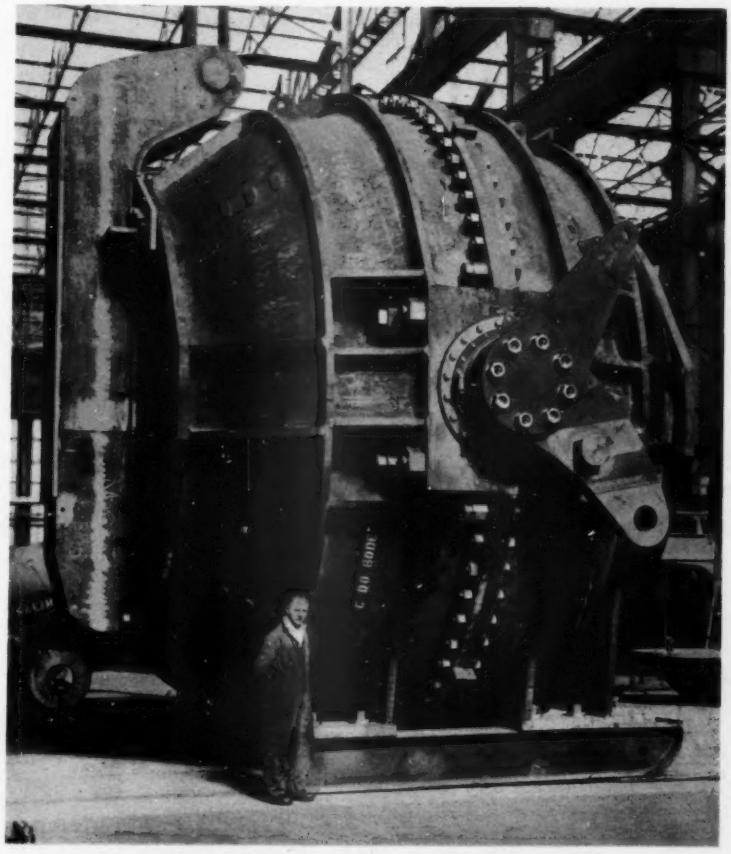


Fig. 1. An English Electric straightflow valve for Castello do Bode

or partial, load changes, the relationship between the time necessary to accelerate the set, namely:—

$$A_T = \frac{Jw^2}{N_{max}} \text{ wherein } J = \frac{GD^2}{4g},$$

in relation to the time necessary to accelerate the water masses in the conduits, namely:—

$$R_T = \frac{LV}{gH},$$

must be considered.

The relation R_T/A_T is called the temporary statism and is of paramount importance in obtaining satisfactory stability and the determination of the governing guarantees.

The meanings of the symbols are as follows:—

A_T	Time, in seconds, to accelerate the machine from zero to normal speed with the full-load torque applied to it.
J	Inertia of the rotating elements.
w	Angular velocity in radians per second.
N_{max}	Full-load output per second in kg.m. or ft.lb., according to the system of units.
G	Weight, in kilograms, of the moving masses.
D	Diameter of gyration.
g	Acceleration due to gravity.
R_T	Number of seconds it takes to accelerate the masses in the conduit to reach the full-load velocity.
L	Length of the pipeline inclusive of spiral and draught tube.
V	Full-load velocity.
H	Net head at the machine.

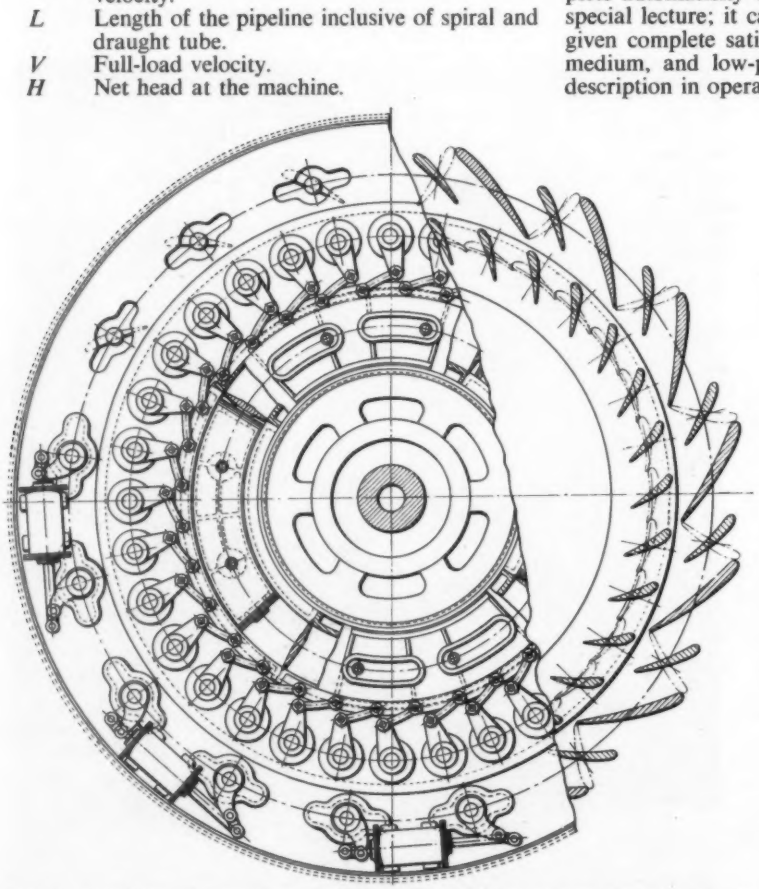


Fig. 2. Auxiliary shutter gear to isolate the turbine runner from the water in the penstock and spiral casing

Comprehensive Automaticity

The elaboration of comprehensive automaticity is due less to the large sizes and complexity of modern plant than to the endeavour to enhance the safety factor for its control under all conditions obtaining in service. It has been found, furthermore, that well-designed automatic governing is far more reliable than the human mind, because station attendants able and willing to concentrate continuously on proper supervision, attendance and maintenance of plant mostly in uninterrupted day-and-night service are extremely scarce, particularly in isolated localities where most plants are situated. Total automaticity must therefore comprise the opening of valves, priming of pressure ducts (casings), bearings and cooling systems, putting under pressure and starting of complete governor gear, release of brakes, starting up to normal speed, synchronising and loading up. The reversed cycle must be observed for normal and emergency shutdown, as various parts of the set and auxiliary gear subject to breakdown or excessive temperature rises—like pumps, main and auxiliary bearings, valves, lubricating, cooling and braking systems—must be safeguarded. It must also provide against runaway and ensure safety against all possible electrical failures.

An exhaustive treatment and discussion of complete automaticity would have to be the subject of a special lecture; it can be stated, however, that it has given complete satisfaction for many years on high, medium, and low-pressure plant of every size and description in operation.

The Governor-Actuator

The automatic governor-actuator can aptly be called the brain of the whole plant, as it controls the speed, load and pressure variations. Upon it depends the safety and uninterrupted service of the plant. A governor-actuator must ensure maximum safety under all conditions of service, high sensitiveness with freedom from vibration and "hunting," compactness and freedom from wear, that is, lost motion, foolproofness, easy accessibility, sturdiness, simplicity of every part, and standardisation so as to be adaptable to every kind of service and every size of plant. Our automatic governor-actuator is made up of three main parts:—

(1) The centrifugal device or governor head.
(2) The actuator gear, with which is combined the double - acting return - motion gear or compensating device.
(3) The oil-pressure relay and and main steering valve through which the oil pressure is distributed to the servomotor.

The governor also comprises a number of accessory parts which permit synchronisation through speed adjustment by hand and remote control, several safety devices in case of oil pressure or drive failure, the necessary starting and stopping devices, both hand-operated and automatic, and a dial tachometer.

The centrifugal device is of the hydraulic type and comprises two compensated flyweights in cam form, which control the differential pressure on one side of an oil-pressure relay by regulating the oil discharge through two nozzles connected with this differential pressure chamber, the piston of which revolves with the flyweights. The latter are suspended by two springs and linked together by two coil springs by which the centrifugal forces developed in rotation by the flyweights are counterbalanced. The centrifugal device contains neither fulcrum pins nor knife-edges, and its relay piston moves axially while rotating and while completely immersed in oil. The flyweight cams regulate the piston by controlling a thin oil film at the nozzles. The device contains no parts subject to wear and is extremely sensitive. It rotates in two ball races which have no influence on its sensitiveness.

The actuator gear and compensating device are concentrated on one single pivoting lever, which has a treble movement as follows. It transmits the movement of the rotating pendulum pin to the operating valve underneath by pivoting, thus causing the relay of the main operating or steering valve to move in accordance with the speed. A small arm on the sleeve which supports the actuator bridge is in continuous contact with the hydraulic return motion or compensating device connected with the servomotor. The latter neutralises the steering valve after the initial operating movement by means of inclined compensating rails mounted on the actuator bridge, this being the secondary pivoting movement. The compensating rails are also pivotally adjustable so that the temporary statism or damping can be adjusted to suit any plant conditions. The third and translatory movement is imparted to the actuator bridge by the second and mechanical return motion device by means of a cam and roller, which brings about the permanent speed variation or permanent statism of the governor. This is adjustable by hand by a simple cam in continuous contact with a roller on the actuator bridge mounting. It will be remarked that all contacts always bear in the same direction so that no lost motion can develop without immediately being compensated. This is important for the elimination of "hunting."

The return motion or compensating device is of the hydraulic type and operates by means of a compensated and spring-loaded neutralised dashpot connected by pipes with the servomotor piston. It cannot develop lost motion and its operation is asymptotic in both the closing and opening directions. It makes it possible to operate the turbine with the same regularity and steadiness for any degree of statism down to zero when there is no difference in speed between full load and no load ("isodrome" regulation).

The governor is completely boxed in, dustproof, foolproof and is practically free from wear and tear.

Straightflow Valves

For the purpose of completeness, I want to add a word on our straightflow type of valve and its purpose and design.* It consists of a hollow hemispherical member provided with a circular hole identical in diameter to the bore of the penstock. It pivots between the spherical outer and cylindrical inner bodies of the valve case, the latter being a prolongation of the penstock; thus there is formed between the inner and outer bodies a space within which the spherical valve member can pivot about two cylindrical shafts.

When the valve is fully open the circular hole fits the bore of the penstock exactly. When closed the solid portion of the hemispherical valve member completely closes the cylindrical passage; the hemispherical valve member is, therefore, a shield of great strength.

The operation of the hemispherical valve member both on closure and opening is again asymptotic by means of a travelling control diaphragm in the same way as our cylindrical balanced type of valve. The purpose of this asymptotic operation is again to obviate any detrimental water pressure fluctuations. Amongst some outstanding examples, one is the 11 ft. diameter straightflow valve for Castelo do Bode (Fig. 1), the largest valve of this type in the world; another is the 7 ft. diameter straightflow valve for Cavado at the top of the pipeline after the tunnel. A special type of patented packing makes all these valves drop-tight.

The Auxiliary Shutter Gear

This auxiliary shutter gear consists of a number of swivel vanes arranged within the stay vanes of the speed ring. It enables the distributing apparatus and the turbine runner proper to be isolated from the water in the penstock and spiral casing, without resorting to a stop valve at the power house. When

*See WATER POWER, July 1952, page 170.

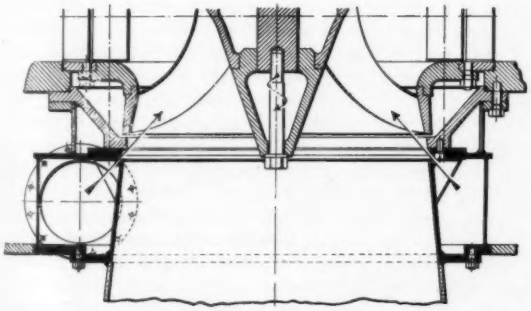


Fig. 3. Vertical shaft arrangement of hydraulic brakes

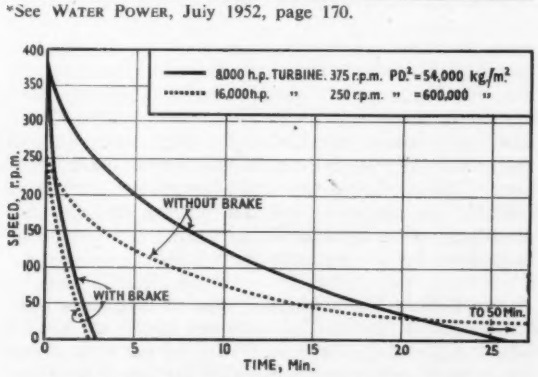


Fig. 4. Deceleration curves with and without hydraulic brakes

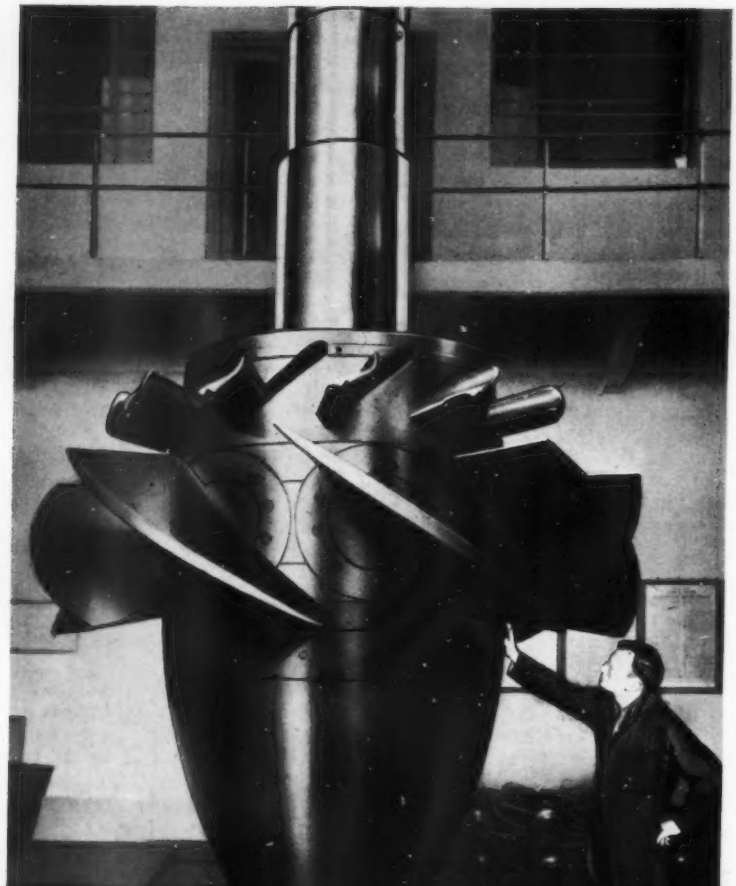


Fig. 5. Feathering-propeller runner with braking vanes in the active position

these shutters are closed, it also allows the existing turbine feeder ducts or penstocks to be used at any time for discharge without resorting to extensive head works or a bypass canal. The swivel vanes of this auxiliary shutter gear bridge the fixed stay vanes of the speed ring; when open they enhance the correctness of the intake vortex, and when closed they make possible the inspection of the turbine and the dismantling without interfering with the irrigation requirements.

Hydro-Brakes for Various Types of Machines

Impulse Wheels.—The runaway speed of impulse wheels amounts to between 80 and 85 per cent. above the normal synchronous speed. This figure is not so dangerous and problematical as the runaway speeds for reaction-propeller and particularly feathering-propeller machines, but it must be catered for so that the turbines and the generators can withstand it with an adequate margin of safety. As stresses increase as the square of the velocity, the stress at normal operation rises nearly 3·5 times for 85 per cent. overspeed. The considerable increase of the centrifugal stress is not the only inconvenience, as the voltage of the generators increases far more than proportionally with the speed increase, and unless the necessary precautions are taken the tension in the windings could vastly exceed the test figure. There is, therefore, every interest to keep the runaway speed as small as possible.

The hydro-brake for impulse wheels is made for the purpose of shutting a machine down quickly by means of a counter jet impinging the runners in the reverse direction to the normal rotation. Naturally this cannot be used to prevent or diminish the runaway speeds; even if made automatic it would diminish the well-known runaway figures to an imperceptible degree. The impingings of a jet on the runners in the reverse direction is in any case rather a crude braking device. We, therefore, thought of a device to improve on this by once again applying the theorem of relativity of Coriolis which shows that for increased speeds part of the jet traverses the runner wheel without working; if this part of the jet is appropriately caught and led back on to the runner it diminishes the runaway speed very appreciably so that it does not exceed 50 per cent. above normal synchronous speed.

Reaction and Propeller Turbines.—The hydro-brake for reaction and propeller turbines uses the runner wheel itself as a brake drum by impinging upon it from the exit side with a number of jets discharged from a small auxiliary spiral case. The effect of this hydro-brake is to bring all these machines, up to the heaviest types, to rest within about three minutes, thus preserving the bearings, including the thrust bearings, in case of overheating, lack of lubrication, or other danger instead of having to wait till the machines come to rest on their own accord, which may be up to an hour or more.

Automatic Hydro-Brake for Feathering-Propeller Turbines.—This device is designed to restrict the well-known runaway speeds which obtain on propeller and feathering-propeller runners which reach two, three, four or even more times the normal synchronous speed. In the case of a machine operated by a feathering-propeller runner of close to 400

specific speed metric the runaway speed reaches about 2·35 times normal, and for a runner wheel operating at 635 specific speed metric it attains 3·1 times the normal. It appeared to be imperative to create a device which could obviate such dangerous conditions, and our automatic hydro-brake embodies a number of backwardly inclined vanes pivotally mounted on top of the runner wheel and retained during normal speed in a position flush with the hub by a ribbon or by breaking pins. The moment the speed exceeds 40 to 60 per cent. above normal, these vanes, by centrifugal force, are projected outwards into the water stream, exercising a powerful braking torque on the rotor. The action of these vanes is completely independent of the normal automatic governor.

The overspeed depends in the first place upon the resistance of the rupturing link, which can be designed and tested so as to give way at a given predetermined overspeed so that this hydro-brake will act with absolute certainty. In an alternative design the vanes can be made self-resetting by means of springs. This permits the brake to be regularly and rapidly tested without requiring the turbine to be dewatered. The operation and effectiveness of both the breaking-link and self-resetting types of hydro-brake are, of course, identical.

D.S.I.R. Hydraulics Research

The Hydraulics Research Board* was set up in 1947 and Sir Claude Inglis appointed as Director of this new D.S.I.R. organisation. Unfortunately several years were lost before a suitable site could be acquired and it was not until 1951 that Howberry Park, near Wallingford, was bought and plans could be made for its development. Wave basins, flumes and an experimental channel are now nearing completion but it does not appear likely that the station will be finished before 1957.

The report states that some of the most important work of the organisation will be that on coast erosion. At present little scientific guidance can be given to authorities concerned, and the whole problem needs systematic study as some of the expedients at present adopted to prevent erosion have actually been found to be harmful.

Models will constitute the principal tools that will be used to solve problems. A model of the River Forth, for instance, was built to find out the probable effects of constructional work that was proposed by the Admiralty, and another model is being used to discover the best way of training the low-water channel of the river. On this model a new type of tide generator is being used. Developed at the station, it can reproduce any tide curve automatically. The profile of the curve is simply fed into the machine on a roll of paper. Cameras with automatic control which take pictures at intervals have also been employed in these experiments. A film taken in this way makes changes in the low-water channel obvious.

The most important model investigation with which the station is concerned is that on the deep-water channel of the Thames. Half a million pounds is spent every year on dredging to maintain this channel from the docks to the sea. Two models have been built by the P.L.A. on the advice of the Director. The objective of the experiments is to find ways of reducing the cost of dredging and stopping siltation.

The value of preliminary investigation, the report states, was shown by some experiments done on a model of the River Eden at Carlisle. It was proposed to construct a weir by building cofferdams. The experiments proved that this method of construction would have caused irreparable damage to the river bed and it was abandoned.

Work on coastal erosion has been begun in a tank 54 ft. long and 10 ft. wide. The first problem to be studied will be the long-term effect of sea walls on the beaches in front of them. This tank is equipped with a wave generator and two large wave basins are being built, in one of which both currents and tides can simultaneously be generated.

For all these experiments the station has had to develop new instruments and techniques. They include the tide generator in use on the River Wyre model, water-level meters of various kinds, and controls for the injection of solid material into the tides to simulate silt. A patent has been taken out on a cheap type of flowmeter which consists of a submerged weir in the line of flow.

* "Hydraulics Research 1947-51." Published for the D.S.I.R. by H.M. Stationery Office, York House, Kingsway, London, W.C.2. Price 3s. (75 cents U.S.A.).

Aura Power Station, Norway

Aura Power Station, at Sunndalsfjord on the west coast of Norway, near Kristiansund, is now nearing completion. This project has had a long and chequered history as the civil engineering work was started before 1914 but the outbreak of war stopped operations. Nothing more was done until the Germans occupying the country decided to complete the station, but the Norwegians were not at all helpful and work was again suspended in 1943. At the end of the war Aura was still very incomplete although the first four turbines had actually been made.

Now, however, the first two 37,500 kVA 500 r.p.m. horizontal 10,500 V generators are nearing completion at the Trafford Park works of the Metropolitan-Vickers Electrical Co. Ltd., where two similar generators and two of 62,500 kVA at 428 r.p.m. for the same station are also under construction. A further generator is being manufactured by the General Electric Co. Ltd. The Pelton turbines for this plant are being supplied by Escher Wyss Limited.

The power from Aura will feed Möre and Romsdal about 25 miles away, and Tröndelag about 100 miles distant, but a great deal of power will be used for an aluminium works which is to be built at Sunndalsrora in the vicinity of the station.

The catchment area supplying the water is 330 sq. miles in extent and includes a number of lakes which will be dammed for regulating purposes. A tunnel 17 km. long leads from the final lake in the series to the power station, forming a net drop of 2,250 ft. The power station itself is situated underground, two large halls having been blasted out of a mountain 3,600 ft. high. Access is gained by two tunnels each about 300 yards long. When Aura is completed it will be one of the largest hydro-electric stations in Europe, with a far greater output than that contemplated originally, and it will help to maintain Norway in its position as the country with the highest *per capita* consumption of electricity in the world.

The Volta River Scheme

We give a summary of the proposals for the hydro-electric section of this important scheme, on which agreement has now been reached.

THE scheme under which the United Kingdom Government, the Gold Coast Government, and the Canadian and United Kingdom aluminium producers would develop large scale aluminium production in the Gold Coast, has been set out in a White Paper* published last month. Under the scheme the resources of water power and bauxite in the Gold Coast are to be developed to produce aluminium at an ultimate rate of 210,000 tons a year, the total capital expenditure to secure this output being about £100 million initially, and rising ultimately to £144 million. Its completion would guarantee the United Kingdom industry additional sterling-area supplies of aluminium at competitive prices to meet rapidly growing requirements for which it is considered unwise to rely on other sources.

It is now proposed therefore to set up a Preparatory Commission at once to follow up the work which has been done already and to examine in greater detail the chief problems which would have to be overcome.

The Volta River, which constitutes the principal drainage system of the Gold Coast, has a total length of some 1,000 miles from the head waters of the Black Volta to the sea. The catchment area of the river system is approximately 150,000 sq. miles, of which 61,500 sq. miles (roughly 40 per cent.) lies within Gold Coast territory including the trust territory of Togoland, and 88,500 sq. miles lies outside the Gold Coast in French territory. The Black Volta rises in the French Ivory Coast and flows north-east and then south to form the western boundary of the Gold Coast Northern Territories, and thence east to join the White Volta some 300 miles from the sea. Below this confluence there are two main tributaries, the Oti and the Afram. The accompanying sketch map shows the general geography.

About 75 miles from its mouth at Ada the Volta passes through the Akwapim Hills, the country up river being flat. The gorge through these hills provides the most promising site for a dam.

* "Volta River Aluminium Scheme," Cmd. 8702. Price 9d. net. H.M. Stationery Office.

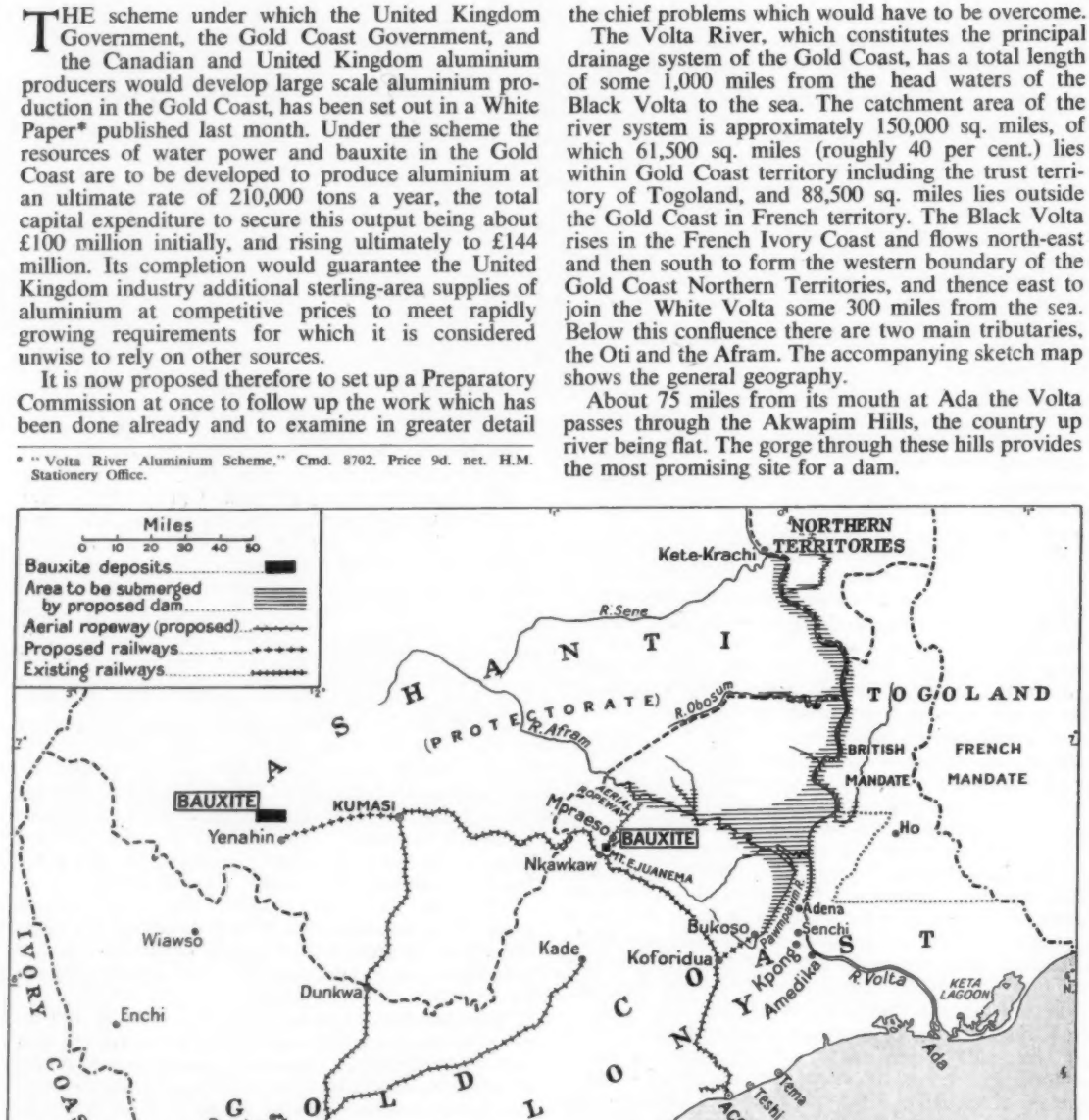


Fig. 1. Sketch map outlining main features of the Volta scheme

The possibility of developing water power from the Volta has been considered at various times during the last few decades. In 1924 the Gold Coast Government drew up proposals for the construction of a dam at Ajena in the Akwapim Hills for generating power for the production of aluminium, and in 1938 Mr. Duncan Rose started a detailed survey and obtained certain concessions. The war interrupted this survey in 1939 but in 1945 a company—West African Aluminium Limited—was formed, with Mr. Rose as chairman, to carry the scheme forward. In 1949 Aluminium Limited of Canada acquired an interest in this company.

In 1950 a joint mission of Aluminium Limited and the British Aluminium Company made a further detailed study of the scheme prepared by West African Aluminium Limited and reported in January, 1951, that it was a sound enginering proposition and could produce aluminium at an economic cost.

Meanwhile the Gold Coast Government had decided that the development of the Volta River Basin should be viewed as a whole and that a comprehensive investigation and report should be obtained before any further rights to develop the power undertaking were granted. Accordingly in October, 1949, they engaged Sir William Halcrow and Partners to undertake a survey of all aspects of the Volta River development. The terms of reference covered hydro-electric power at Ajena and/or Bui, irrigation and drainage of lands in or near the catchment of the River Volta, navigation on the river, transport and port facilities.

After a preliminary report dated 25th July, 1950, Sir William Halcrow and Partners submitted a final report on 15th August, 1951, which set out a scheme for the development of the Volta Basin. So far as it related to aluminium production this report formed the basis for the subsequent discussions between representatives of the United Kingdom and the Gold Coast Governments, of Aluminium Limited, and of the British Aluminium Company which took place in October and November, 1951, and in May, 1952, in London, and in June, 1952, in Accra. The purpose of these discussions was to consider the conditions under which the two Governments and the aluminium companies might jointly participate in a scheme for aluminium production in the Gold Coast. Sir William Halcrow and Partners and Cooper Brothers and Company, the chartered accountants engaged by the United Kingdom Government as advisers on the financial aspects of the scheme, were represented.

The discussions were necessarily exploratory in character but the following scheme was arrived at.

This scheme envisages the construction of a dam and power station at Adena in the gorge through the Akwapim Hills. This would raise the water level to a maximum height of 260 ft. above sea level and would create a lake with an area of some 2,000 sq. miles. The geologists of the Gold Coast Government have agreed that the dam and reservoir proposed are geologically sound. The exact extent of the reservoir will not be known until a detailed survey has been completed but it is known that the water can be safely raised to this level. From records of the river flow which are available over a twenty year period it is estimated that the discharge could be regulated to give a continuous rate of 35,700 cusec. The draw down from the maximum level would be limited to 25 ft. By cutting through the Senchi and Kpong rapids below the dam to lower the tail water level it is calculated that an output of 564,000 kW of firm electric power could be developed.

It has always been realised that any major development of the Volta Basin would only be economic if an adequate demand could be found for the available power. Existing and estimated future demands for electric power in the Gold Coast are insufficient to justify the hydro-electric power without a heavy power consumer like aluminium production as the main outlet. It is intended to set up an aluminium smelter in the vicinity of Kpong, some 12 miles from the dam site. After allowing 50,000 kW for other users in the Gold Coast, the power available from the hydro-electric installation would be enough to produce 210,000 tons of aluminium a year. The smelter would draw its major raw material, bauxite, from reserves within the Gold Coast. Deposits of bauxite at Mpraeso and Yenahin, which would be worked to supply the smelter, are estimated to exceed 200 million tons, sufficient for about 200 years production at the maximum output of the smelter.

The establishment of an aluminium industry of this size would necessitate the construction of a new port conveniently situated to serve its needs. Takoradi is the only major port in the Gold Coast. Accra, next in size, has already reached the limit of its capacity and is unsuitable for further development as a port. While Takoradi has recently been extended, it is already evident that a new major port is urgently required to meet the general needs of the expanding Gold Coast economy. Sir William Halcrow and Partners recommended that a new port to serve both the general and the aluminium needs should be constructed at Tema about 20 miles east of Accra. The Gold Coast Government, after obtaining a second opinion, have decided to proceed with the construction of a new port at Tema whether or not the scheme as a whole is undertaken; preliminary work is now in hand.

In addition there would need to be a considerable development of communications. Existing roads would need improvement and new roads would have to be built. It is expected, however, that the main burden of new traffic would fall on the railways. The new port at Tema would have to be linked by rail to both Accra and the smelter at Kpong. The bauxite would also be moved by rail, and new lines from Yenahin to Kumasi and from Koforidua to Kpong would be required.

The aluminium smelter and bauxite mines would be managed by private enterprise, the aluminium companies and the Gold Coast Government sharing in the provision of the equity capital. The smelter company would be responsible for the construction and operation of the smelter and the development and operation of the mines. The smelter company would also be responsible for constructing the townships at the smelter and mines. The land required for the smelter would be acquired by the Gold Coast Government and would be leased to the smelter company for a period of 80 years plus a period of not more than three years for the construction of the smelter.

Production Programme

It would be the intention of the aluminium companies to erect a smelter of 210,000 tons a year capacity as rapidly as conditions permit. Their willing-

ness to participate is based on the conviction that the scheme would be capable of rapid expansion. In the first place, however, a capacity of 80,000 tons a year would be installed. The aluminium companies would be prepared at the request of the two governments to commit themselves to expand the capacity to 120,000 tons a year within a period of seven years from the date when power first became available unless the two governments subsequently agreed to extend the period. The aluminium companies would further be prepared at intervals of three years to consult with the two governments on ways and means of attaining the maximum capacity of 210,000 tons. If a capacity of 210,000 tons had not been reached within twenty years from initial production, they would undertake to examine the position with the two governments. Failing agreement as to the feasibility of further expansion the power not required for the existing and immediately projected capacity of the smelter could be released to other users. In the event of others contracting for power for the production of aluminium the smelter company would make available to such producers the required quantities of bauxite on reasonable terms.

The United Kingdom and Gold Coast Governments would be jointly responsible for financing the hydro-electric power undertaking as a whole; the Gold Coast Government would be solely responsible for facilities for the distribution of power to other users beside the smelter. The undertaking would be organised as a public utility and the finance would be provided by loans fully secured on the assets. The loans, which would bear interest, would be amortised over a period of eighty years. The Gold Coast Government expect to provide at least £8 million towards the power project proper.

It is proposed that a Volta River Authority and a Volta Electricity Board should be set up by the Gold Coast Government, the former to be responsible for the building of the dam and power station. On completion of the construction work the Volta Electricity Board would assume responsibility for the management of the power undertaking and also for the installation of additional generating units, transmission lines and extensions to the original works.

Certain capital and other expenditure would arise as a result of the creation of the reservoir on matters such as the resettlement of population, clearing and draining marginal lands, clearing navigational channels necessary for maintaining existing communications, and various compensation claims, together with the administrative costs involved. This expenditure would be a charge in the first instance on the power project up to a limit of £3 million. Any expenditure on these items over this sum up to a maximum of £1 million would be shared equally between the Gold Coast Government and the Volta River Authority. The maximum aggregate charge on the power project would be £3½ million.

The interest rate at which loans to the Volta River Authority for the power project would be made has an important bearing on the ultimate cost of power to the smelter, and the aluminium companies have asked that the interest rate should be determined before final commitments to proceed were taken. Two bases for the interest charges have been considered. The charge might reflect changes in the money market; as each instalment of the loan was advanced the rate for that instalment could be determined in the light of market conditions at the time. Alternatively a fixed rate for all the borrowings might be settled at the time when the decision was made to proceed with the scheme; the Government or Governments would then take the risks of any rise and receive the benefit of any fall in interest rates. The aluminium companies would be given the option of deciding which method they preferred at the time commitments were undertaken. They have, however, also pointed out that they would be reluctant to see the project financed entirely by long-term borrowing at a time when interest rates were high, thereby preventing later conversion to a more favourable basis.

Power Utilisation

The supply of power for the smelter would be governed by a contract under which the Volta Electricity Board would undertake to make power available to the smelter up to an amount necessary for the production of aluminium at the rate of 210,000 tons a year for sixty years from the date at which power was first available. The contract would recognise that other users in the Gold Coast would require up to 50,000 kW of the power which would be available. The Gold Coast Government, Aluminium Limited and the British Aluminium Company would share, in the ratio of their respective holdings in the equity of the smelter company, an obligation to secure that the Volta Electricity Board would receive payments amounting each year to its out-of-pocket or operating costs (including interest) in respect of the power contracted for by, and made available to, the smelter company, plus the calculated amount needed in the year to cover *(a)* the appropriate contributions to a renewals fund and *(b)* amortisation of the capital expenditure over 80 years. Provision would be made for the extension of the amortisation period by agreement if there were unavoidable delays in construction. In the initial stages these payments would be abated by the amount of sales to consumers other than the smelter company. The charges for power so sold would be detailed in the power contract. At the time a smelter capacity of 120,000 tons a year was attained the Gold Coast Government would declare what quantity of power (over that needed for an annual output of 210,000 tons of aluminium) it wished to reserve for public consumption and would from then on relieve the smelter company of the appropriate proportion of the cost of power production. Power not so reserved by the Gold Coast Government would be available during the currency of the power contract to the company. The guarantee of the power contract by the participants in the equity of the smelter company would remain in force until the smelter company had installed capacity for production of 210,000 tons of aluminium a year and had profitably produced at substantially that rate for five years.

Estimates of Cost

It is at present estimated that the cost of public works to be undertaken by the Gold Coast Government including port, roads, railways and townships would be £26,000,000, of which the port of Tema is estimated to cost £11,000,000.

The smelter company would require £29,000,000 to develop the bauxite mines, build towns at the mines and smelter, and construct and operate the smelter

at an annual capacity of 80,000 tons. At capacities of 120,000 tons and 210,000 tons a year the corresponding figures would be £39,000,000 and £64,000,000 respectively.

The estimated cost of the power project, revised by Sir William Halcrow and Partners in June, 1952, to take into account rises in wages and salaries in the Gold Coast, is £41,500,000 for 80,000 tons smelter capacity; for 120,000 tons £45,500,000; and for full development £49,500,000. There is margin of error of 15 per cent. up or down on certain items of cost in civil enginering estimates of this kind, and for maximum safety 15 per cent. has therefore been added to these items in order to show the estimated maximum cost. The estimated costs for the various stages of the power project then become for 80,000 tons £45,500,000; for 120,000 tons £49,500,000; and for full development £54,000,000.

These estimates are considered to be as firm as can be expected at a stage when detailed bills of quantities and contract drawings have still to be drawn up and competitive tenders obtained. They are not likely to be substantially different from any others which become available before work on the scheme is actually put in hand, provided there is no general increase in the level of costs.

In the view of the Gold Coast Government there would be adequate reserves of manpower, not only for existing undertakings and the production of subsistence and cash crops but also for the construction work entailed by the Volta project and developments in other parts of the country. The Gold Coast Government are confident that with appropriate wages and conditions, adequate housing, feeding and medical arrangements, there would be no undue difficulty in attracting, recruiting and retaining the required labour force; and that arrangements could be made to this end without dislocating prevailing wage levels.

An agreed timetable would be drawn up and incorporated in a Master Agreement in which the rights and obligations of the parties would be set out. The Gold Coast Government have stated that they would be ready, whenever occasion arose, to defer or rephase other parts of their development programme which seemed likely to conflict with the Volta River Aluminium Scheme in demands on the resources available.

In return for the United Kingdom Government investment in the scheme the smelter company would be under an obligation for thirty years from initial production to offer to buyers in the United Kingdom at least 75 per cent. of the production at prices f.o.b. Gold Coast port not exceeding the sterling equivalent of either the lowest North American domestic price (for ingot or pig) f.o.b. refinery or the Canadian domestic price (for ingot or pig) f.o.b. refinery, at the choice of the aluminium companies to be exercised before final commitments are accepted.

World's Largest Pump-Turbine Unit

Contracts for the largest electric motor and reversible pump-turbine ever built have been awarded to the Allis-Chalmers Manufacturing Company. The equipment will be the heart of a pump-storage project at Hiwassee dam in south-western North Carolina on the Tennessee Valley Authority's power network. It is scheduled for completion late in 1955. In this installation a single hydraulic machine will operate in one direction as a turbine and in the reverse direction as a pump. A direct-connected electrical machine will serve as a motor for pump operation and as a generator for turbine operation. Water from Hiwassee reservoir, driving the unit as a turbine-generator, will add needed energy to the TVA system in peak demand periods. During off-peak periods, when surplus power is available from other plants, the unit will operate as a motor-driven pump to replenish the reservoir.

The reversible pump-turbine will utilise the largest Francis-type runner ever built. As a turbine it will have a maximum rating of 120,000 h.p., and when motor-driven, it will have a pumping capacity of 3·3 billion gallons per day. The pump has more than three times the capacity of each of those serving the Grand Coulee irrigation project, which are at present the world's largest. As a motor the electrical unit will be the world's largest, rated at 102,000 h.p., 106 r.p.m. It is approximately 50 per cent. larger than the motors driving the Grand Coulee pumps. As a generator it is rated 70,000 kVA, 13,800 V.

The BEAMA Catalogue

Exports from the British electrical industry for 1951 amounted to £190 million, and when the figures for 1952 are published it is expected that electrical exports will have reached £210 million, or 7 per cent. of the country's total exports. At this figure Great Britain and the United States are the world's two greatest export nations in electrical apparatus.

To give overseas customers specific guidance as to what Great Britain can offer in this field, the British Electrical and Allied Manufacturers' Association (Inc.), 36 and 38, Kingsway, London, W.C.2, has issued a second edition of the BEAMA Export Catalogue, which boasts 1,000 pages as against the 850 pages of the first edition. Much of the catalogue is occupied by announcements of member firms under the headings of Power Plant; Industry, Transport and Communications; and Domestic and Commercial. An innovation is a Glossary in five languages—English, French, Spanish, Portuguese and German—and a Buyers' Guide, Trade Directory, and Catalogue Index complete the volume. The Association is convinced that the British electrical industry has much of value to offer to the world, whether the goods are assessed on price, on delivery, or on quality.

Women's Engineering Society Discuss Dams. The London Branch of the Women's Engineering Society spent a delightful evening last November when Mr. Peter O. Wolf, B.Sc.(Eng.), A.M.I.C.E., of Imperial College, gave a lecture on "The Construction of Dams." His treatment was largely descriptive and was concerned primarily with concrete dams, although brief reference was made to the earth dam. Gravity buttress and arch dams were described and compared, and the practical problems of excavation, concrete mixing and placing, and shuttering were brought well to the fore. In the latter part of his lecture Mr. Wolf described in some detail the Sloy and Mullardoch dams, in the construction of both of which he had been concerned. The resulting discussion was a very useful one in bringing out some of the practical difficulties of dam construction.

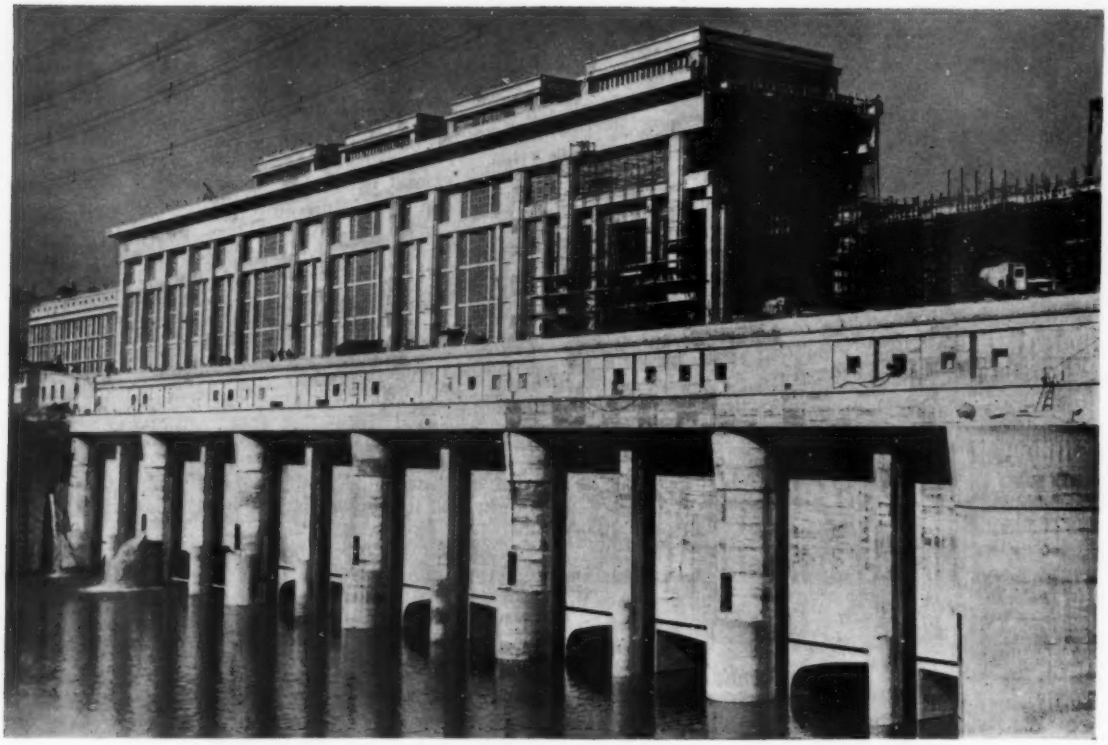


Fig. 10. General view of André Blondel power station

The Rhône Development

Following on the description of Génissiat last month, Dr. Charles Jaeger gives a first-hand account of the Donzère-Mondragon Section.

BETWEEN Donzère and Mondragon there is a fall of about 20 m. (65·61 ft.) and the new power station, which was recently opened and inaugurated by President Vincent Auriol, is the first of four projects to be completed to develop the relatively long distances of the central portion of the lower Rhône. All these projects will involve the construction of bypass canals over relatively long distances. Two of the projects with proposed power stations at Étoile-sur-Rhône and Logis Neuf, have been envisaged but not studied in detail, and the third, Montélimar, is next on the schedule for development. The project at Donzère-Mondragon, however, is from all points of view the most interesting of the four, and it has already been given a wide publicity.* But many aspects of the scheme are less well-known and it gives us an opportunity to point them out.

The Donzère-Mondragon scheme consists of a dam across the Rhône just downstream of the small town of Donzère and the so-called "robinet" of Donzère (literally, "cock," which means here a narrow valley passage or gorge, of historical importance) and an intake on the left-hand side of the river. A 28 km. long canal (17·3 km. headrace, 10,700 km. tailrace) bypasses the Rhône, meanders and short circuits a river length of 31 km. (average river slope 0·75 per thousand). The average gross head is 23·40 m. (72 ft.) and the net head about 22 m.

The dam or weir consists of six openings closed by rubber sealed Taintor gates—the larger one being a navigation passage of 45 m. (148 ft.) width, the other five for flood control with a width of 31·50 m. each. These are quite unusual spans for any type of gate and the navigation Taintor gate is probably a record for Western Europe. (Several rolling gates of 45 m. have been built in Western Europe: two in Germany and one in Norway). The Taintor gates are of a new design with a tilting upper leaf. The normal water

*P. Delattre. L'Aménagement du Rhône et la Construction de la Chute de Donzère-Mondragon. *Travaux*, Paris, Vol. 34 No. 186, April, 1950. *The Engineer*, Dec. 8, 15, 22 and 29, 1950, Oct. 24th, 1952. *Annales de L'Institut Technique du Bâtiment* No. 225. Donzère-Mondragon, Aménagement de la Chute, December, 1951. *La Technique des Travaux* No. 9/10, 1952.

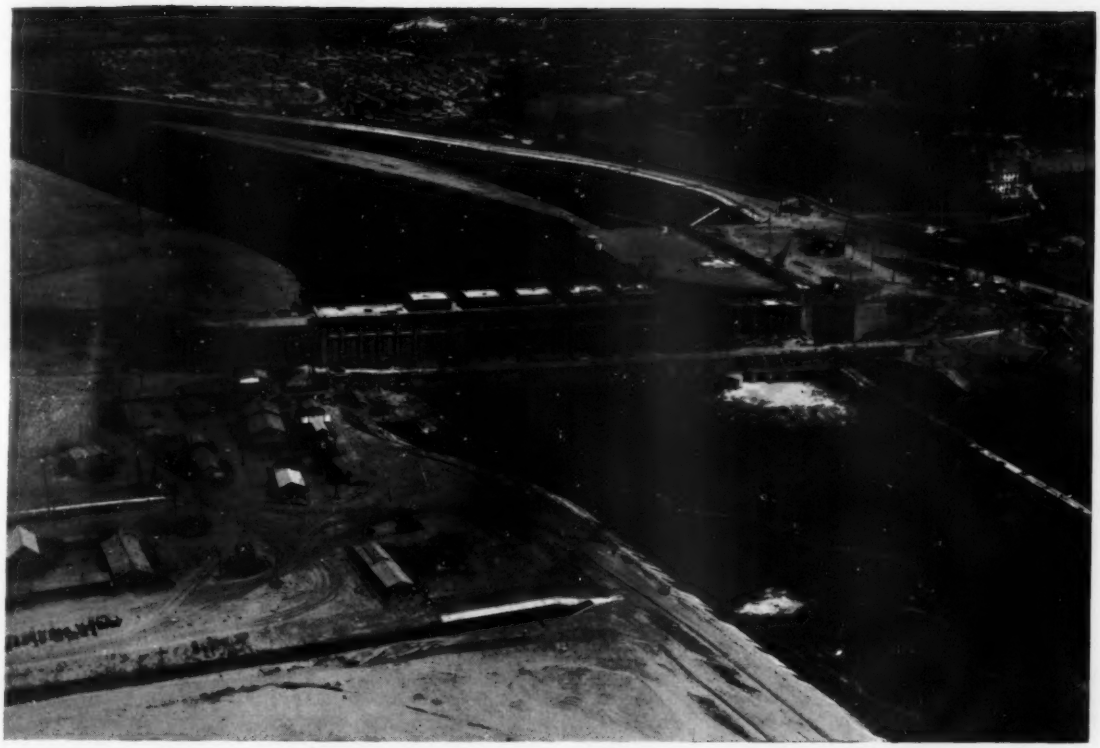


Fig. 11. Aerial view looking upstream showing power station, canal, lock and tailrace

Fig. 12. View upstream of the power station with basin for river traffic in foreground

level at the dam will be at level 58·00 (exceptionally 58·50) which is 5·60 m. above the former low level (52·40) for 560 cu. m. per sec. The back water created by the dam will extend about 10 km. upstream. The normal flood level is at elevation 56·85, corresponding to a discharge of 3,950 cu. m. per sec. Once in 100 years the flood level reached elevation 58·61 and the maximum flood (10,000 cu. m. per sec. to 12,000 cu. m. per sec.) is supposed to reach elevation 63·00.

The geological conditions at the dam site are not very favourable for a construction of this magnitude but there is no possible alternative. On the right bank and on one-third of the length of the dam the foundations are on limestone, but the other two-thirds and the left abutment are on soft blue marl and clayish material incapable of withstanding the effect of bed erosion.

The deepest point of the foundation is below level 38. As the top of the pier is at level 74·50, the total height of the piers is about 36.50 m. The dam sill is at level 49·50.

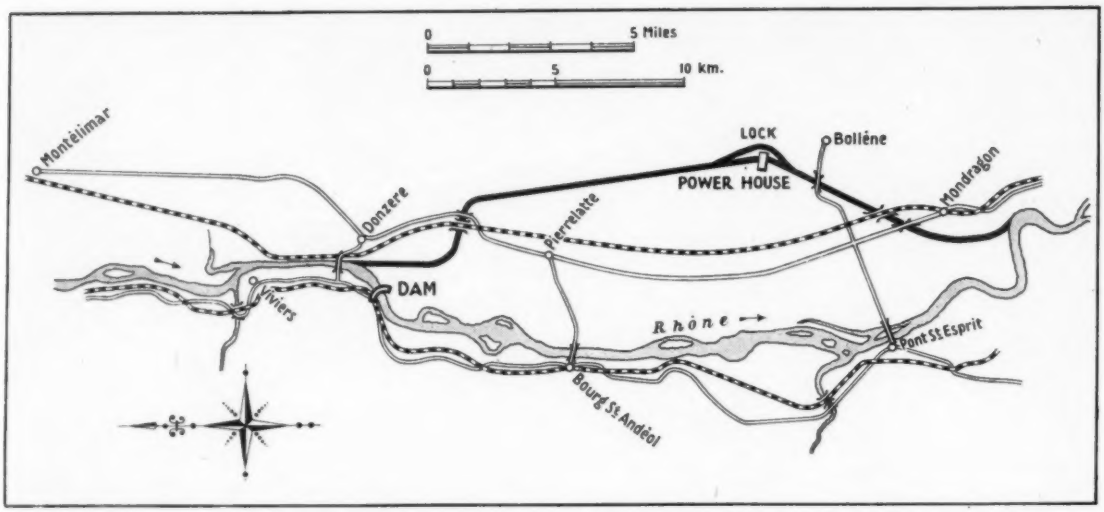


Fig. 13. Sketch map of the Rhône between Donzère and Mondragon showing situation of dam and power house in relation to the new canal

The method of construction for the seven piers varied according to the nature of the foundations and the river depths, the deep water currents concentrating on the left side of the Rhône. The right abutment (No. 1 pier) and No. 2 pier were founded on limestone in open sites behind ordinary cofferdams reinforced by sheet pilings. Pier No. 3 is also on limestone, but was founded with the compressed air caisson method, the steel caisson being erected on an artificial island as usual in quiet shallow water. Piers Nos. 4 to 7 were founded in deep water on marl and clay. The steel caisson of the No. 5 pier was erected on a high scaffold (steel structure) and lowered to the river bottom. Pile No. 7, which forms the left abut-

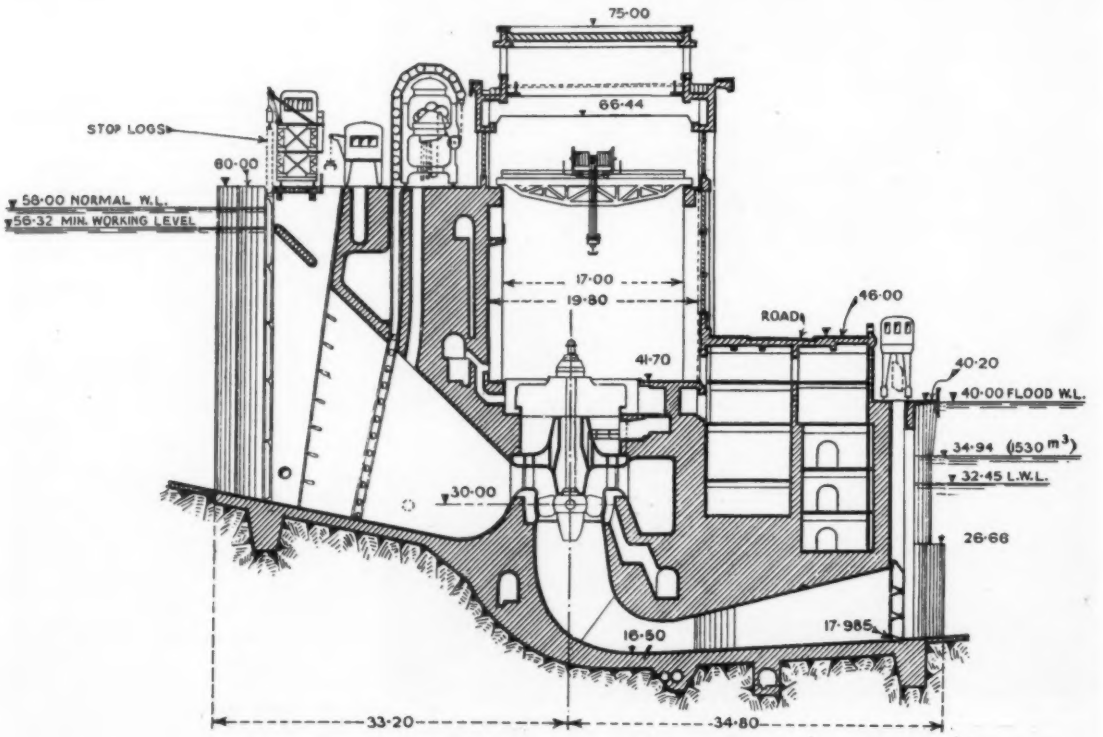


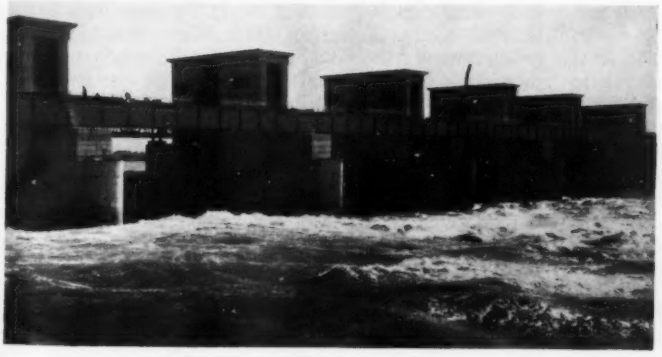
Fig. 14. Sectional elevation, André Blondel power station

Fig. 15 (left). Interior view of turbine hall

Fig. 16 (below left). The two entrances to the diversion canal

Fig. 17 (bottom left). Sluice gates at Donzère capable of passing 423,000 cusecs

Fig. 18 (below). View in lock, looking downstream



ment of the weir, is a reinforced concrete caisson. The greatest difficulties were encountered with piers 5 and 6, which had to be suspended on a floating scaffold, erected on two barges. The caisson was slowly lowered to the river bottom and then down to foundation level. This is a difficult and costly procedure, but a high fixed scaffold structure would have been impossible with river depths varying from 6 to 7 m. and high water velocities. The caissons were $38 \times 8{\cdot}75$ m² and weighed up to 105 tons. In summer, 1949, the large caisson No. 6 near the left river bank was just being hung on its floating scaffold when one of the floats sprung a leak. The scaffold twisted and the whole structure, including the steel caisson, went aground, considerably delaying the construction.

The weir sills between the piers were built by conventional methods in the open behind protecting cofferdams, the difficulty of construction increasing with the depth of the river, being greatest for the large navigation opening on the left bank.

During this whole construction period (1948-1951), floods of 6,000 cu. m. per sec. and even more were likely to occur

Fig. 19. The diversion canal, 475 ft. wide and 32 ft. deep, showing the superelevated banks

Fig. 20. Typical bridges built over the canal

at any time on the Rhône, and actually did occur. In spite of detailed model studies during which the different phases of the methods of construction were analysed, the river bed was eroded during the construction period and had to be consolidated in places and dredged in others, in order to protect the river navigation against rapid currents or danger from shallow water.

The design of the stop logs for dewatering the large navigation gate (45 m. width) was a major problem. Conventional horizontal stop logs are difficult to design for such a width. Prof. Aubert (former chairman of the Board of the Campagnie Nationale du Rhône), who has long experience with the conditions on the river Seine and the navigation weirs there, developed a new type of stop log, where the logs are nearly vertical. I-shaped beams at an angle of nearly 90° to the horizontal weir sill, are placed with their bases at the front of the weir sill and rest on a servicing bridge at the top. They are handled by means of a simple mobile crane. The vertical stop logs are then inserted between two neighbouring "I" beams. The stop logs and beams can be used for any of the six openings, despite their varying width. Only the two stop logs next to the piers are made to fit the openings individually.

Many difficult problems had to be solved when designing the intake to the canal. With a slope of 0·7 per thousand and floods discharging up to 10,000 cu. m. per sec. in the Rhône, there is obviously danger of débris entering the headrace canal. Because of navigation requirements, the intake was designed in a line with the river in advance of the bend on which the intake works were to be built. This is obviously a most undesirable direction with regard to débris transportation. Two separate intakes were designed, one for navigation with sill at level 54·50 (width 100 m.), the second for hydro power, with sill at level 52·50 (width 80 m.). Two-thirds of the discharge to the main headrace canal will pass through the hydro-power intake. The gates and the canal are designed for a normal water level of 58·00 m.o.d. at the dam, the canal dam crests being at level 60·00 m.o.d. In case of floods reaching higher than 60·00 o.d. or when flushing of the Rhône bed has to be carried out to scour the deposited débris, the intake works are sealed and the whole structure is protected by high banks reaching above the highest flood level.

Difficult model studies were carried out by the Compagnie Nationale du Rhône, on a distorted scale, and later by the Laboratoire National at Chatou (run jointly by the Ponts et Chausées and Electricité de France) without model distortion, to find an appropriate shape for the intakes in order to avoid the entry of sand and gravel.

The principle developed at this laboratory was to provoke artificial eddies all along the sills of both intakes, especially that of the hydro-power intake, these eddies being intended to protect the intakes and to divert all the débris towards the weir for scouring. Any sand or gravel deposited in the canal will be removed without emptying it.

It has not been necessary to employ model tests to specify the design and construction of the headrace canal. The width at the bottom of the canal is 83·30 m. with 10·30 m. depth and 145·10 width at water level; it is thus wider than the Suez Canal. The water velocity in the canal will be 1·30 m. per sec. At water level (which will be fairly constant), bituminous and soil cement have been used for the protection of the side banks, but there is no other protection for the canal bed. Although the canal is enclosed by embankments its course has been chosen so that it is never completely superelevated.

The construction of the canal involved the building of two new railway bridges, one over the headrace and the other across the tailrace canal. Three main road bridges and six secondary road bridges traverse the canal. All these are very large structures with an average span of about 600 ft. The canal course cuts five rivers, some of which are quite considerable in flood periods. Furthermore, the former irrigation canal of Pierrelatte occupied part of the

path and even crossed it. The rivers were passed under the canal, using several syphons of exceptionally large dimensions, or alternatively they were diverted. The Pierrelatte canal was similarly diverted, and an entirely new system of drainage and irrigation canals had to be designed. Upstream of the power house, along the headrace canal, the new canals are mainly for drainage; downstream, along the tailrace canal, the lateral canals are for irrigation.

During the summer of 1952, seepage could be observed at several places along the headrace canal. The lateral drainage canal, parallel to the main navigation and power canal, collected the leakage water. It is most probable that some repair work will have to be done in some places along this canal. It is expected that silt deposition will ultimately seal off the seepage. Before the diversion of the Rhône water through the canal, the ground water table in the wide alluvial plains of the Rhône was being fed directly by the River Rhône and in addition to this by the old Pierrelatte irrigation canal. As long as the main canal bed remains pervious, feeding of the table through the canal bed will take place, but if sealing of the main canal bed occurs, the wide ground water nappe will have to be fed otherwise. It is foreseen that this will have to be achieved with the lateral irrigation canals which will feed the ground water nappe through vertical wells with an horizontal area of 10×10 sq. m.

The power house at the end of the headrace canal (Usine André Blondel) comprises the machine room, the bypass structure and the lock. The total length of these works is 340 m.

On the first designs of the Compagnie Nationale du Rhône, the power house was envisaged well downstream, but because of the geological conditions, it had to be moved upstream to a point where hard sandstone offered an excellent foundation. The amount of excavation work, both for the power house and tailrace canal was, however, greatly increased.

The draught tube foundations are at level 15 m. O.D. or about 48 m. (158 ft.) below the ground level. This figure gives some measure of the excavation work which had to be carried out. The total height of the building reaches 59 m. (195 ft.).

A period of only four years and two months was estimated for the construction of the power house, the bypass structure and the lock. In this short period 3,330,000 cu. m. of earth and rock had to be excavated (to a depth of 48 m.) and 410,000 cu. m. of concrete had to be placed. Work began in the difficult post-war period of 1947-48. It was possible to begin concreting on secondary items as early as December 1948. In 1950 about 250,000 cu. m. a month of silt and sand, and about 180,000 cu. m. of rock were being excavated! In July 1951, 340,000 cu. m. of concrete had already been placed. In summer 1952, the first turbine was running.

The machine room is a very spacious and impressive building, 184 m. long, 17 m. wide, with main floor at elevation 41·70 m., equipped with six Kaplan turbines each developing 70,000 h.p. and discharging 255 cu. m. per second (8,000 cusecs). The turbine diameter is 6·10 m. (20 ft.), and the weight of the runner is about 120 tons. Each turbine is directly coupled to a 50,000 kW (107 r.p.m.) generator. The turbines were manufactured variously by the Société Alsthom-Charmilles, the Société Escher Wyss & Co., and Fives Lille. The alternators are by Alsthom and Jeumont. At the transformer station, which is several hundred metres to the west, the voltage is stepped up to 60,000 V (for use on the electrified Lyons-Marseilles railway), and to 220,000 V for transmission to the French grid. The transformers are not a contract of the Compagnie Nationale du Rhône, but of Electricité de France.

It is expected that the Usine André Blondel (300,000 kW) will produce 2,000 million kWh a year, half of which will be in winter.

The machine room is entirely in reinforced concrete. It will be noted that the frames supporting the two cranes (2×250 tons) are independent of the structure supporting the walls and the roof. The frames were built first, the cranes being a matter of urgency for the erection of the machinery.

Walls and roof were built later, using chiefly precast elements. The roof consists of 240 precast and prestressed U-beams, 16·50 m. long, 0·8 m. high, and 0·73 m. wide. They weigh 7·5 tons each and were placed by transport cables.

Each turbine intake consists of three openings 5·20 m. wide and 17 m. high, with grooves for the stop logs in front of the trash racks, and a third set of grooves for the emergency gates.

The design of the generator support is unusual. As can be seen on Fig. 14 part of the load is transmitted directly through the cylindrical generator support to the speed ring and stay vanes and to the foundations. Another part of this load is transmitted to a structure which can best be described as an enlarged turbine cover structure which looks like part of an hyperboloid having the generator shaft as vertical axis. This finally transmits the load to the speed ring and stay vanes. The two structures, vertical cylinder and hyperboloid, are connected beneath the generator by a horizontal spider structure to assist the load distribution. No further details on this new design were available.

The unlined spiral casings are constructed in reinforced concrete and are 20 m. (65·6 ft.) in diameter. The spiral roof is about 3 m. thick and heavily reinforced. The reinforcement bars are anchored to the generator support, with coupling sleeves for prestressing. They are calculated to take the whole torque from the generator. Few reinforcements could be seen connecting the spiral roof to the cylinder supporting the generator. Presumably the moments produced by water pressure in the spiral casing will be transmitted to the generator cylinder by the massive concrete cross section.*

On the upstream side of the power house building, the emergency gate for rapid closing of an overspeeding turbine is worth mentioning. It is a completely new design which can best be seen on Fig. 14. This gate is an articulated sluice gate; when in the lifted position it is lying in a semi-circle over the transport gantry used for transporting the gate from one turbine intake to the other. It closes by gravity against the full pressure but is probably not absolutely tight. The stop logs which glide in the grooves upstream of the trash racks can then be closed under balanced pressure. There is only one emergency closing sluice gate for the six turbines, the emergency gate being transported from one turbine to another.

Immediately to the east of the power house, and

* Ch. Jaeger: Design of unlined spiral casing for low head stations. WATER POWER, Feb./March, 1952.

in line with it, is the bypass structure. In the case of a short circuit provoking the sudden closing of all the turbines, a translatory wave would be produced in the headrace canal, which might be dangerous to the unlined canal, but would most certainly endanger any barges navigating the canal. Similar waves would develop on the tailrace canal.

To avoid the formation of these translatory waves, each turbine is electrically connected to a Taintor gate, which opens or closes synchronously with the closing or opening of the turbine guide vanes. These six Taintor gates are 5·20 m. wide and 3·50 m. high. Their axis is at an elevation of 41·50 m. Under a hydrostatic pressure of 16·5 m. they discharge 255 cu. m. per sec. when fully open. There is, nevertheless, a time lag between the nearly synchronised movements of the turbine guide vanes and the Taintor gates of the bypass. In order to reduce the effect of this time lag, the Compagnie Nationale du Rhône are studying the possibility of temporarily connecting the generator to a water resistance. For the time being no details have been published about this proposed method.

The energy of the water discharging through this bypass is destroyed over a dentated chute.

It will be noted that all the structures of the Usine A. Blondel attain a level of 60·0 o.d. or higher; so also do the dams on both sides of the headrace canal, which are, therefore, above the normal water level (58·00 m.). There is no need for any supplementary regulation of the discharge at the upstream end of the canal (at the intake). As soon as translatory waves are suppressed, there is no need for permanent spilling at the downstream end of the canal. The canal losses were estimated at 0·87 m. for a discharge of 1,530 cu. m. per sec. for the six turbines.

The lock is 195 m. (640 ft.) long and 12 m. (39 ft.) wide, and has a lift of 26 m. (85·3 ft.), believed to be the world's highest, and the speed of 1·60 m. per min. at which the barges are lifted or lowered exceeds by 40 per cent. the previous world record. More impressive than this figure is the absolute quiet and steadiness of the water surface when moving up or down. This is the result of a new design for water adduction to the lock sump, which was extensively tested on models. The lock gates are cylinders which are lowered at the lock head and raised at the lock downstream end.

The dimensions of the tailrace canal are similar to those of the headrace (58·70 m. width at the bottom, 126·30 m. width at water level when the water depth is 12·40 m.). Most of the excavation work in the tailrace canal was carried out by marine dredgers. These were assembled on site and lodged in a specially made basin fed by water from the underground water table. Each had a capacity of about 10,000 cu. m. per day, the spoil being delivered some 80m. distant. As the water level in the tailrace frequently varies with the discharge in the Rhône, a special erosion protection is required. A concrete revetment was used, consisting of articulated units 3 ft. wide, 24 ft. long and $3\frac{3}{16}$ in. thick, reinforced in two directions by $\frac{3}{16}$ in. wire. These units were made in a casting yard comprising 120 casting beds of 22 blocks each. The units remained in the casting beds for 16 hours and then were removed to stock piles where they remained for an additional 7 days. The moving was accomplished by vacuum lifter (3 × 48 ft.) and the unit placed with a floating derrick on the canal banks (with a slope 3 : 1).

The Donzère-Mondragon project has involved the handling of the largest volume of earth as yet undertaken in Western Europe (this being about half of the excavation necessary for the Suez Canal in its present state). Engineering equipment included 21 large excavators, 34 American-built earth-moving machines, comprising scrapers drawn by caterpillar tractors and self-propelled wheeled scrapers, and in addition, a loader was employed which ploughed the excavated material on to a belt-type elevator from which it was discharged into motor trucks. This loader is capable of handling 500 cu. m. of material an hour. Furthermore, 84 large motor trucks were used, 10 large drag lines, 5 marine dredgers, 6 soil excavators and a considerable amount of contractors' railway equipment for the transport of material.

The table below concerns the excavation of the canal and gives an idea of the magnitude of the work.

Types of machines	Excavation Million cu. yards	
Scrapers, loaders and wagons ...	5·3	
Shovels, small drag lines ...	5·3	
Large drag lines	17·2	
Floating dredges	33·0	
Bucket chain excavators ...	5·3	
Total ...	66·1	(50·6 million cu. m.)

Of this 11,500,000 cu. m. were for the headrace canal and 23,500,000 cu. m. for the tailrace canal.

Further to this 50 million cu. m. of excavation work the following quantities of materials were used:

Cement	260,000	tons
Reinforcement bars and steel sheet pilings	50,000	,,
Structural steel	30,000	,,
Concrete	800,000	cu. m.

At Génissiat, it was possible to carry out the civil engineering works in a region which was very thinly populated, but the Donzère-Mondragon project has necessitated the expropriation of about 5,000 acres of land and more than 100 farms. At the busiest time 7,000 people were employed, nearly all of whom had to be accommodated in camps; as many of them were accompanied by their families, suitable accommodation had to be provided for 10,000 people.

Three of the generator units have now been put to work and a fourth and fifth will be ready in 1953, while the sixth is expected to be in service in 1954.

Blaw Knox Limited. A new series of illustrated and attractively coloured leaflets issued by this firm deals respectively with the BK-40 Scraper (Publication BK-174, superseding No. BK-107); BK-80 Scraper (Publication 143/2, superseding BK-143); BK-90 Scraper (Publication BK-172); and the BK-120 Scraper (Publication BK-144/1, superseding BK-144).

"Bestos" A.V.C. Cables. Publication No. 318, received from British Insulated Callender's Cables Limited, gives full particulars of their Bestos A.V.C. cables which are constructed to withstand temperatures between 50-70°C. (122-158°F.), showing typical applications, constructional details, and illustrating specimens that have undergone severe flame tests. These cables are supplied in single and multicore types for voltages up to 6,000 and tables are given to show sizes, current ratings, etc., of representative varieties.

A New Joint Seal

ONE of the problems which have always plagued engineers is how to make an absolutely watertight joint between adjacent masses of concrete. In answer to this problem what is called a "labyrinth waterstop" has been devised by Mr. L. F. Harza, the well-known consulting engineer of Chicago, who has for many years been engaged in designing dams, power houses and other hydraulic structures. The accompanying sketches show the construction of the seal and the method of application. To install the seal in construction joints all that is required is to tack the outer edges of the strip lightly to the form and pour the concrete around it. There is nothing to get bent or knocked out of alignment and the concrete readily fills the dovetailed corrugated grooves whether a vibrator is used or not. After the forms have been stripped the concrete from the second pour fills the grooves on the other side so forming an interlock which is at once flexible and watertight.

Geon polyvinyl chioride resin from which the seal is made is understood to have substantial advantages compared with rubber for this purpose. In the first place it is easily welded, the only thing necessary being to heat the ends with a hot plate or to play a flame over them until the material is softened, after which the ends are simply pressed together and a 100 per cent. joint results. In the second place the resin has an almost infinitely better ageing characteristic than rubber. In fadeometer tests—essentially exposure to an extremely brilliant ultra-violet light—the Geon showed only superficial changes after 2,000 hours of exposure, estimated to be equivalent to about 240 years of sunshine.

Labyrinth seals are made in two sizes, 5¼ in. and 3¼ in. wide, the larger size being recommended for dams and mass concrete structures intended to have a resistance to water pressure equivalent to from 50 to 200 ft. head, while the smaller size is intended for pressures up to 50 ft. of head. The large size costs $2.50 per foot and the smaller $1.25 per foot, with reductions for quantities of over 1,000 ft.

The labyrinth is now being used on some important projects. The U.S. Bureau of Reclamation has tested it in their Concrete Laboratory at Denver* and found that it prevented the passage of water up to a pressure of 100 lb. per sq. in., equivalent to a water head of 231 ft. They then separated the joint by a distance of ½ in. to simulate actual field conditions and found that the watertightness was not in the least impaired. This may appear surprising but it is obvious that the interlock must be drawn tighter with increasing joint separation, so that, in fact, with normal separation the seal is tighter than it is before shrinkage takes place. The labyrinth waterstop is being marketed by Water Seals, Inc., of Chicago.

* Concrete Laboratory Report No. C-614 of the Design & Construction Division, Bureau of Reclamation.

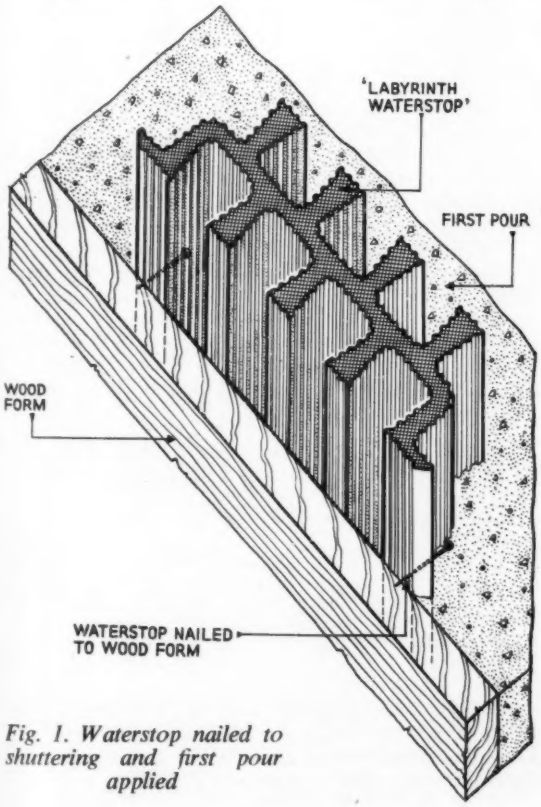


Fig. 1. Waterstop nailed to shuttering and first pour applied

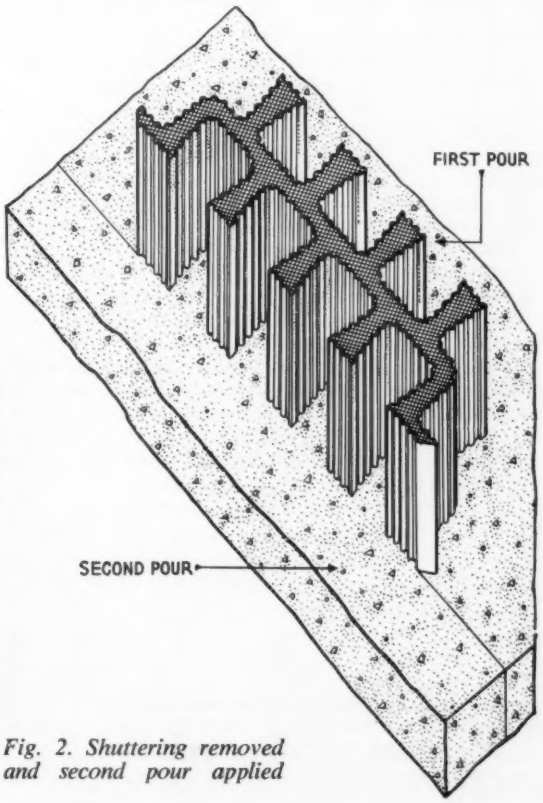


Fig. 2. Shuttering removed and second pour applied

Abstracts from the World Technical Press

Differentiating Losses in Francis Turbines

The original is a report on extensive tests carried out at the Brommat hydro plant by M. Fontaine, assisted by M. Campmas, for the purpose of ascertaining the distribution of losses in Francis turbines,

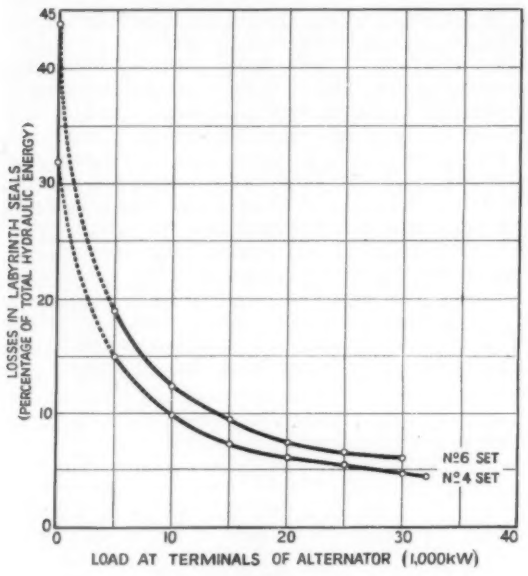


Fig. 1. Energy lost in labyrinth seals in Nos. 4 and 6 sets

the ultimate goal being to arrive at a more accurate assessment of the efficiency of these machines.

These losses are divided as follows:—

(a) Friction and turbulence losses in the sluice valve, casing, distributing and runner proper;
(b) Losses in labyrinth seals;
(c) Losses in draught tubes.

The authors issue a reminder, however, that the total efficiency of the turbine also has to take into account the losses caused by the friction of the shaft on the bearings.

The loss resulting from friction or leakage in the labyrinth seals, and the residual energy not recovered by draught tube action, are closely investigated and measured; by deducting this loss from the total losses, the amount of energy dissipated in the remaining parts of the turbine, *i.e.* sluice valve, distributor, casing and runner, is obtained.

It is not claimed that this method permits perfectly accurate results to be arrived at, as the extreme irregularity of the flow in the draught tube renders absolute accuracy impossible. The figures obtained supply, however, averages which agree to such an extent as to permit valuable conclusions to be drawn. It has long been known that the recovery of the energy lost in the draught tubes is far from being satisfactory, and that there is still room for improvement in this connection. The Brommat investigations show that this particular loss to be relatively great in Francis turbines, and that manufacturers have still extensive opportunities before them to develop new designs.

A closer investigation of this problem, extending to turbines of various sizes and speeds, combined with research on the influence of other factors than the discharge, such as head and suction head, would undoubtedly furnish more reliable results, especially with the help of more accurate measuring apparatus.

The method used at Brommat can easily be applied to Kaplan turbines if accurate temperature measurements can be taken, and even to Pelton wheels, in which latter case the losses would have to be divided into nozzle and runner losses, as well as residual hydraulic energy dissipated. (E. Fontaine and P. Campmas, *La Houille Blanche*, Vol. 7, No. 2, April 1952, p. 269, 14 pp., 15 ff.)

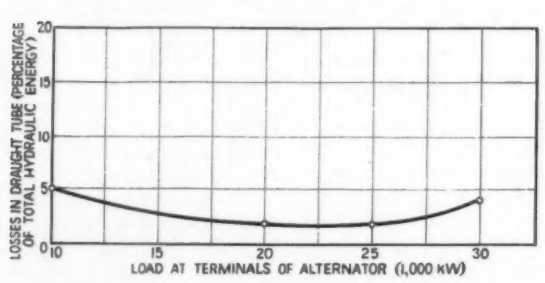


Fig. 2. Energy lost in draught tube, No. 4 set

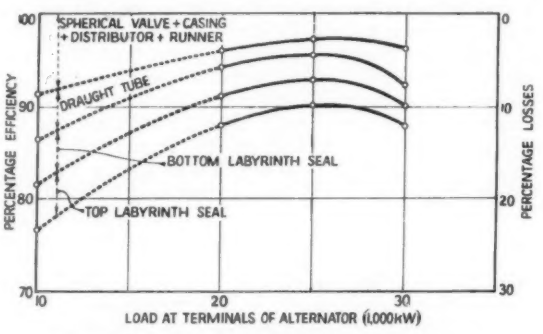


Fig. 3. Distribution of losses in No. 4 set (net average head 240 m.)

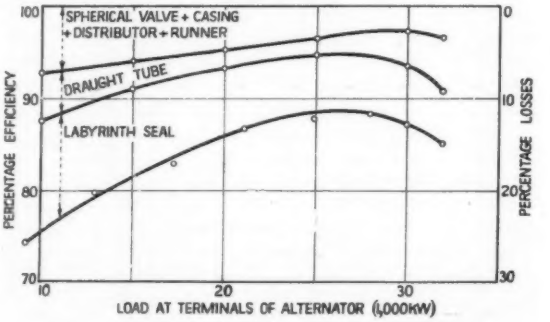


Fig. 4. Distribution of losses in No. 6 set

Heavy-Duty Concrete Compactors

A review is given of the evolution in design and construction of heavy-duty concrete vibrators in Germany from the depth-vibrator to the most up-to-date surface compactors, and of their possibilities of application in modern dam building.

Vibrators used for compacting coarse-aggregate concrete weigh 2·5 to 4 tons, and the grating-like vibrating attachments have a working surface varying between 1·60 and 2·50 sq. m. Special attention is devoted to giant compactors, particularly suitable for large rock-fill; these powerful machines weigh from 10 to 20 tons, and their vibrating grating operates at the rate of 3,000 vibrations per min. The accompanying diagram shows an improved design of this type of compactor in which the compacting attachment, no less than 1·85 m. in diameter, is actuated by a series of detachable vibrating cells; the advantage of this design, in comparison to the single-gear vibrator, is that each cell can easily be removed and replaced by a spare cell if required, so that stoppages resulting from failures in the vibrating mechanism are reduced to a minimum.

If lifting gear of adequate power is not available on site for handling the compactor, the use is suggested of a revolving crane which can be easily dismantled, or of a crawler-mounted crane. For very large dams, the author advocates compactors moving in the same way as the crabs of travelling cranes on long-span bridge-type structures which shift on two rails. These rails would, of course, have to be strong enough to overcome without risks unevenness and wide troughs in the concrete pours. (Dipl. Ing. C. Rappert, *Die Wasserwirtschaft*, Vol. 42, No. 4, Jan. 1952, p. 148, 6 pp., 8 ff.)

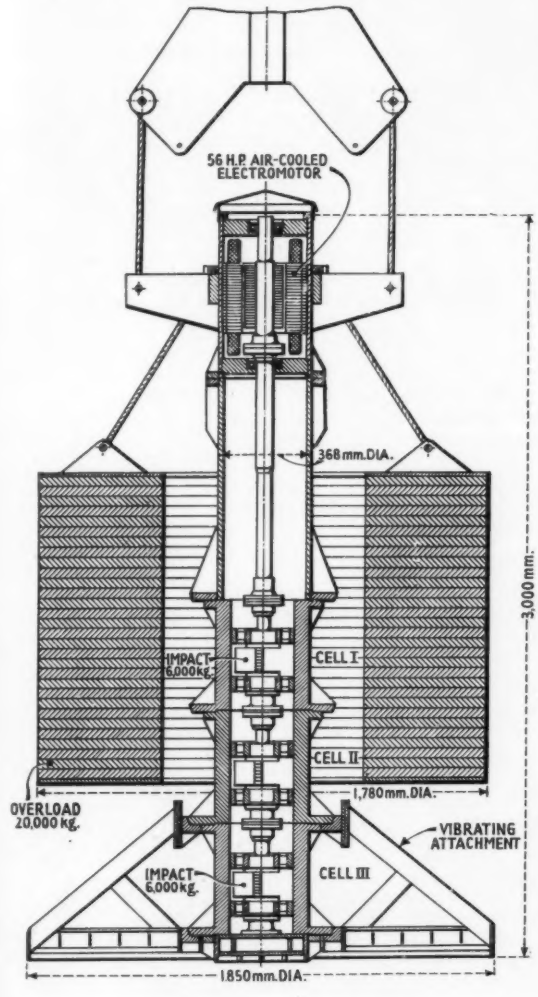


Fig. 1. Multi-cell giant compactor

Ganges-Kobadak Development East Pakistan

This scheme may be considered as the first part of the Brahmaputra-Ganges multi-purpose project, though it can operate independently. The project, which will benefit an area of 2·75 million acres in East Pakistan, involves the following works:—

(a) A 60 mile long canal between the Ganges and Kobadak River;

(b) Three pumping stations to ensure the irrigation of the Khulna and Jessore Districts;

(c) A hydro-electric station and a thermal plant to provide power to the pumping stations, the former operating at flood periods, the latter during the low-water season.

In addition, the upper Kobadak will be dredged about 25 miles to provide fresh water to the southern Khulna district, tidal water will be kept out by repairing the bunds in the Khulna area, and 2,000,000 acres of land will be prepared for irrigation.

Preliminary investigations have already been made, and surveys are in progress.

This project, which entails a total expenditure of almost 190 million rupees, is of the utmost importance to a region in which fluctuations in food production bring about conditions bordering occasionally on famine, and where the shifting of the main river channels has left an area of dead and dying rivers which is being invaded by salt water in its southern

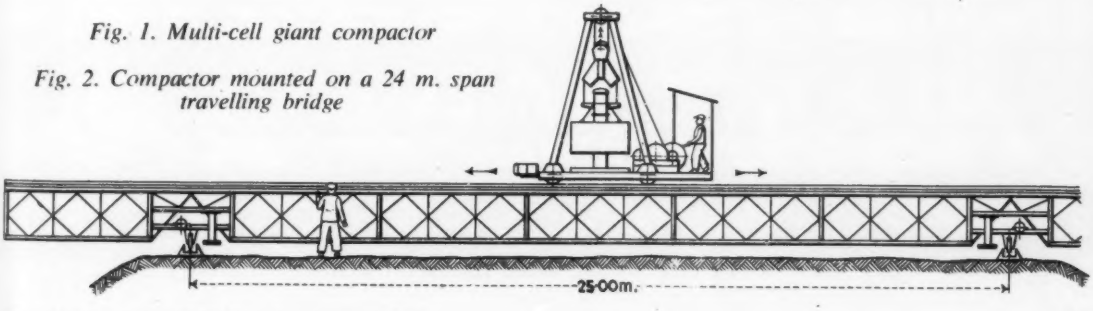


Fig. 2. Compactor mounted on a 24 m. span travelling bridge

part. It is expected that a guaranteed water supply during the six to eight dry months will produce double and perhaps treble cropping. (Dr. W. J. von Blommestein, F.A.O., *Indian Journal of Power and River Valley Development*, Vol. 2, No. 5, April 1952, pp. 23-24.)

Modern Grouting Technique

In this article a comprehensive survey is given of modern grouting methods and techniques, especially in connection with dam construction. The author deals first with the various grouting agents which are divided into four main groups: solutions, emulsions, suspensions and pastes. Other paragraphs are devoted to preparatory geological investigations, drilling of grout holes and equipment involved, impermeability tests, grouting proper and grouting appliances. (Dipl. Ing. Hans Werner, Koening, *Die Wasserwirtschaft*, Vol. 42, No. 4, January 1952, p. 120, 12 pp., 18 ff.)

Rejuvenating an old Hydro-Plant

Holyoke, Massachusetts, with a population of 55,000, was literally built on water power and, since 1849, has derived power from a still operative three-level canal system. As far back as 1889, this system developed 23,000 h.p., and the town had become the largest paper producer in the United States. The first step towards complete electrification was taken in 1905, when Station No. 1 went into operation; it has grown since into a five-unit, 7,640 kW hydro plant utilising the fall between the second level canal and the river. Station No. 2, a 2,900 kW hydro plant, was put on the line between canal levels one and two in 1924. The

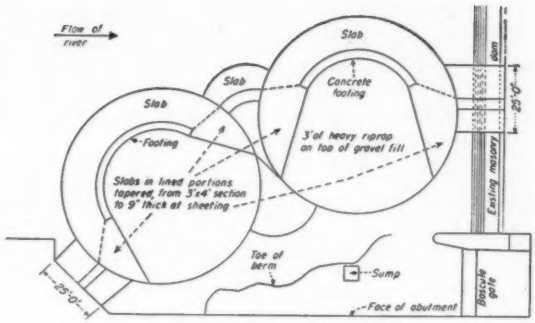


Fig. 2. Plan of cofferdam

latest addition to the scheme is the 15,000 kW Hadley Falls Station which stands at the dam, outside the canal system. There are hardly any uncommon features in this new power plant apart, perhaps, from the unusually large diameter (28 ft.) of the reinforced concrete penstock, but the cofferdam used in dewatering the intake construction area for removing an existing concrete abutment deserves a special mention. It consists of two cells each 76 ft. 4 in. in diameter—a record size. It was the existing river-bottom conditions which influenced the decision to resort to two cells of such diameter, instead of a greater number of smaller units which might have curved the cofferdam farther upstream into the submerged remnants of the old Connecticut River dam at this spot. (*Engineering News-Record*, Vol. 148, Jan. 10, 1952, No. 2, p. 32, 4 pp., 7 ff.)

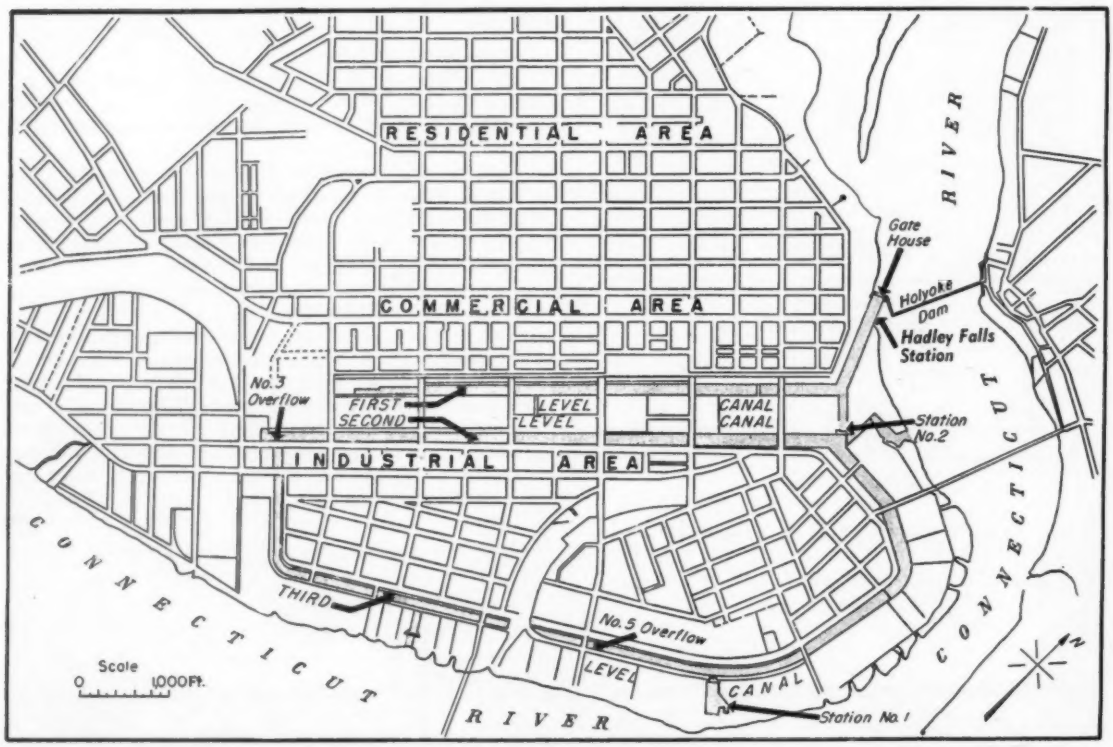
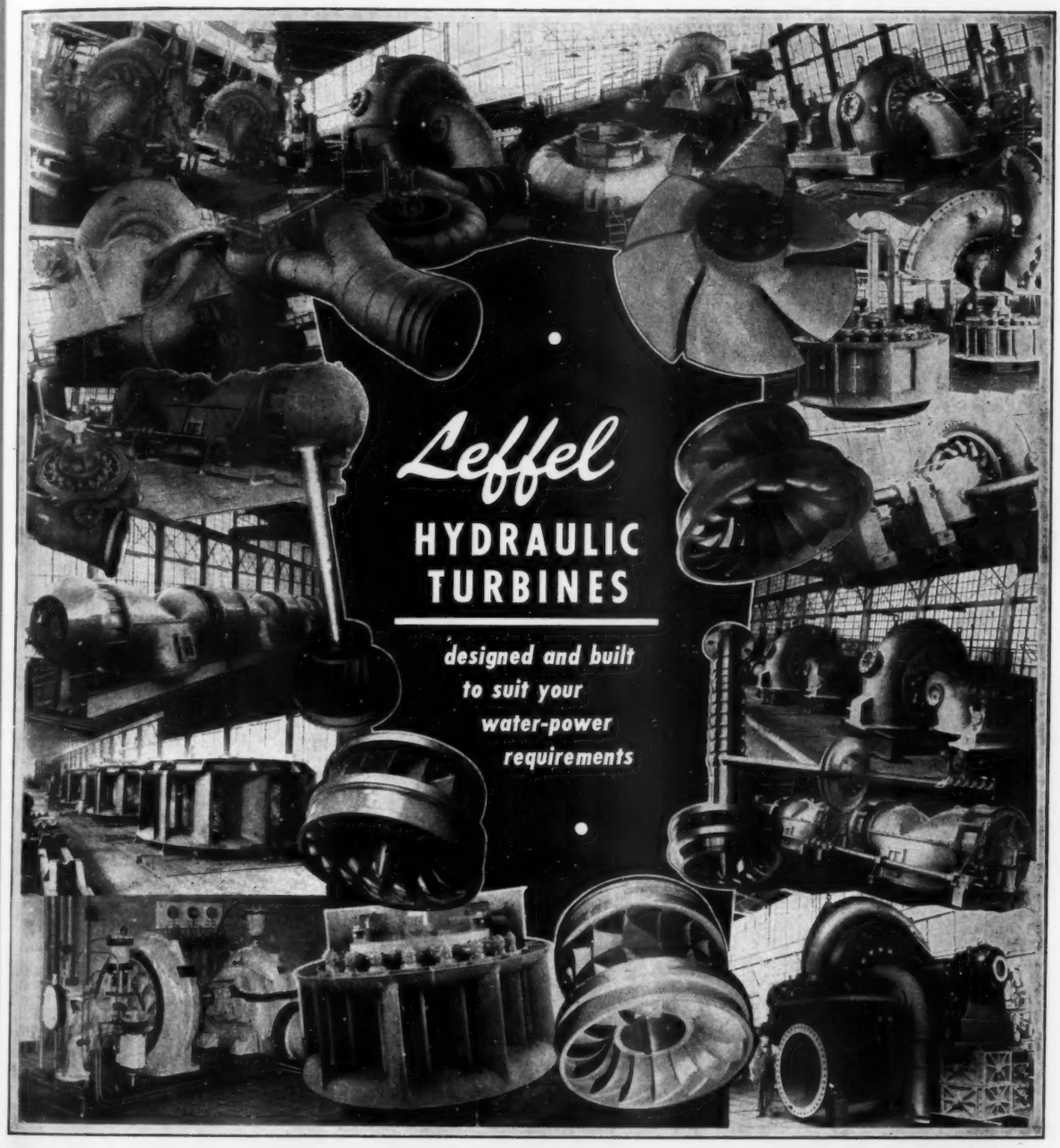


Fig. 1. The Holyoke canal system which governed the layout of the city



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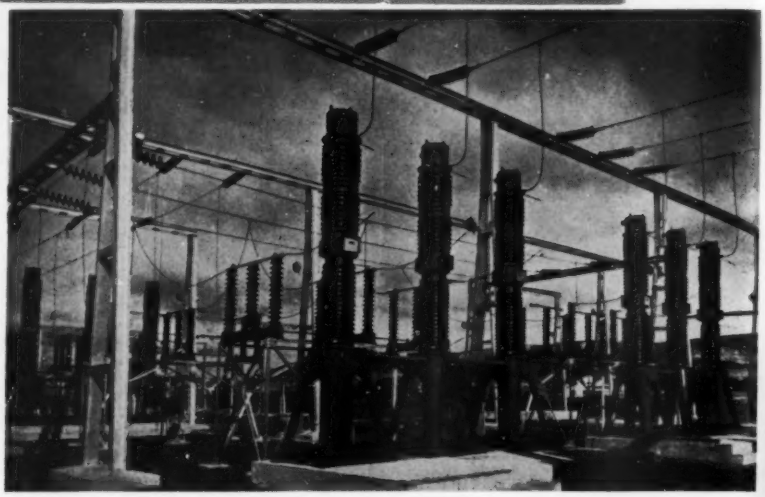

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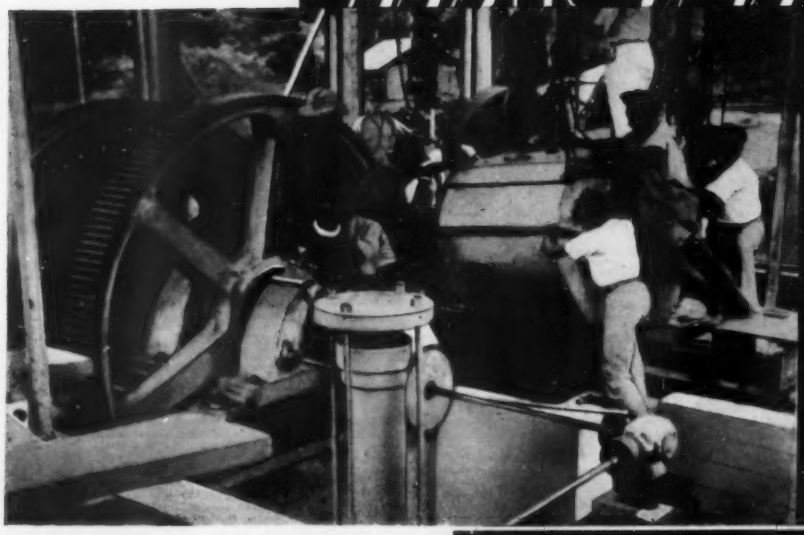

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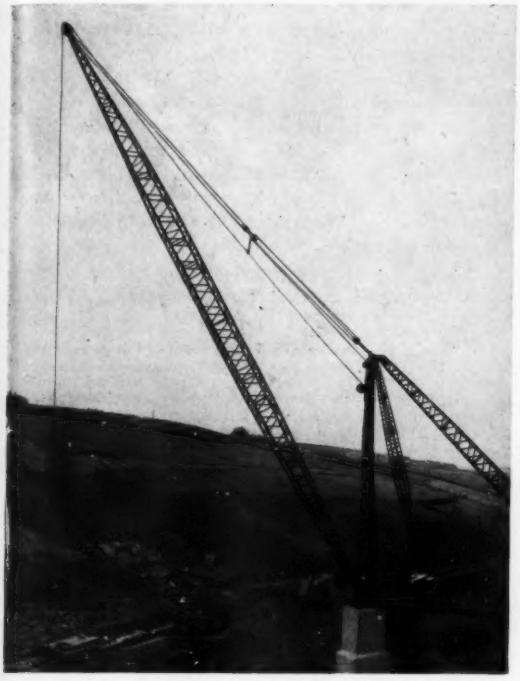

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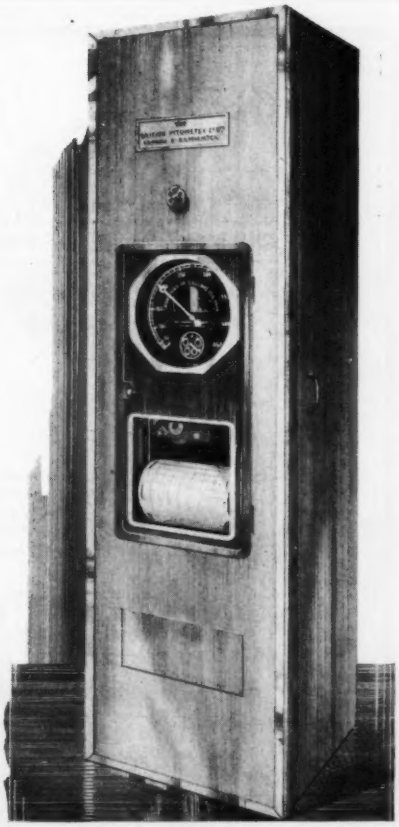

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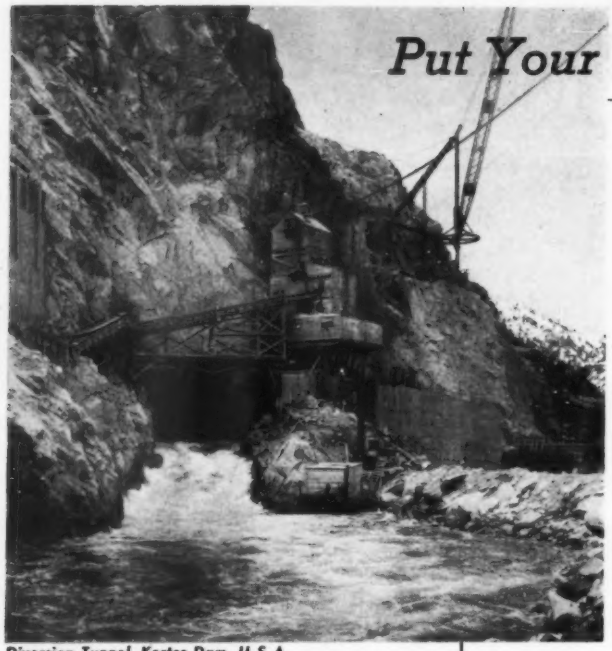

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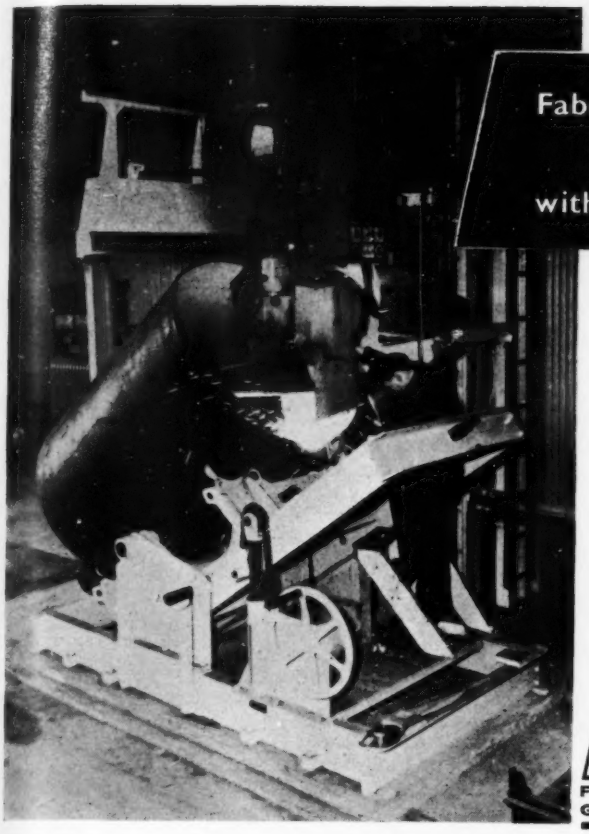

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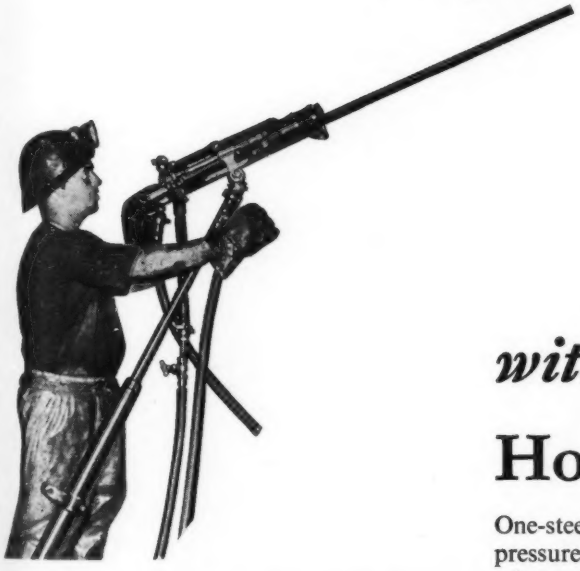

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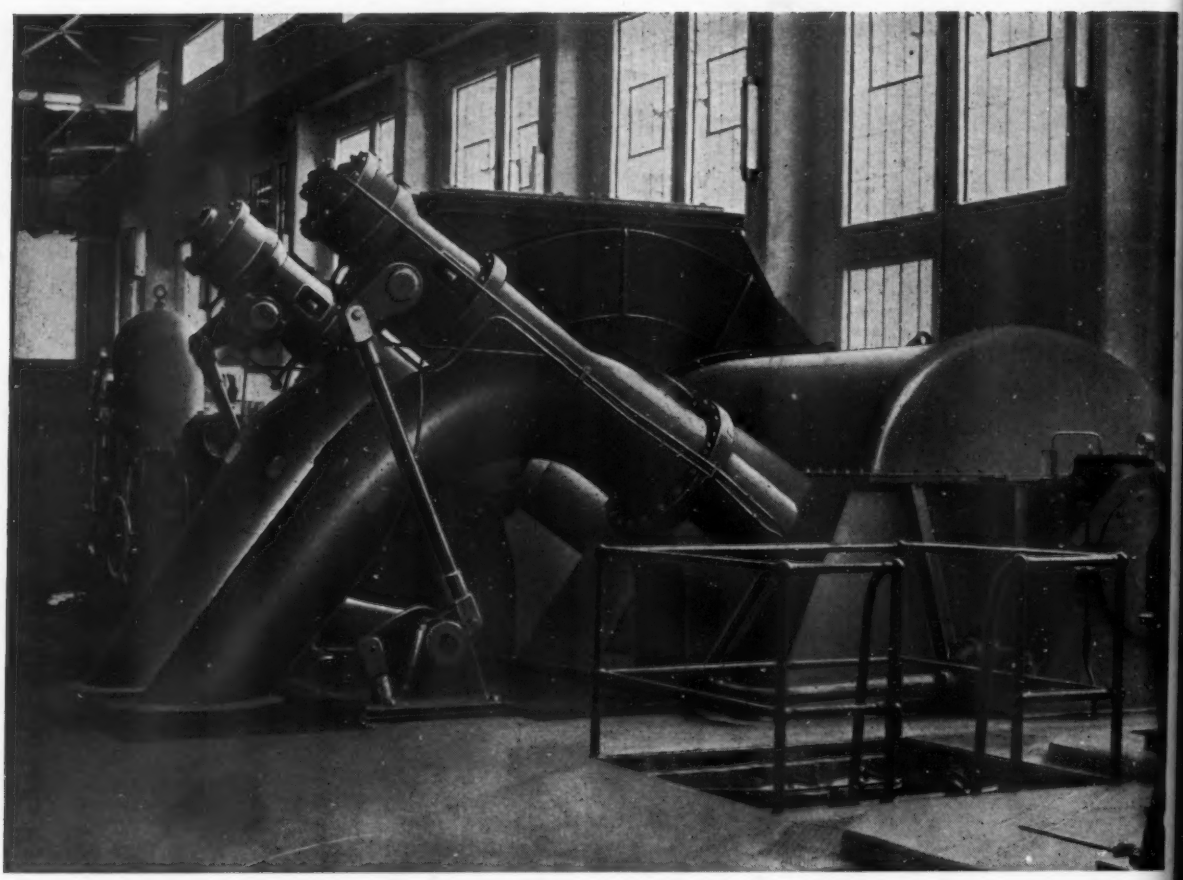

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